2699

1146

RD&E CENTER

Technical Report

No. 13175

20011102 151

Evaluation of an Aluminum Replaceable Pad Track for the M-1 Main Battle Tank

Contract Number DAAE 07-84-C-R054

September, 1988

Daniel F. Carbaugh and Mark A. Holtz
Aluminum Company of America
Forging Division
1600 Harvard Avenue
Cleveland, OH 44105-3092

By

AN-41714

U.S. ARMY TANK-AUTOMOTIVE COMMAND
RESEARCH, DEVELOPMENT & ENGINEERING CENTER
Warren, Michigan 48397-5000

NOTICES

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188 Exp. Date: Jun 30, 1986

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release Distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) 13175
6a. NAME OF PERFORMING ORGANIZATION Aluminum Company of America Forging Division 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION DCASMA, Cleveland
6c. ADDRESS (City, State, and ZIP Code) 1600 Harvard Avenue Cleveland, OH 44105-3092	7b. ADDRESS (City, State, and ZIP Code) A.J. Celebreeze Federal Bldg. 1240 E. Ninth Street Cleveland, OH 44199
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army TACOM 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAE 07-84-C-R054
8c. ADDRESS (City, State, and ZIP Code) Warren, MI 48397-5000	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Evaluation of an Aluminum Replaceable Pad Track for the M-1 Main Battle Tank

12. PERSONAL AUTHOR(S)
Daniel F. Carbaugh and Mark A. Holtz

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 11/84 TO 05/86	September, 1988	

16. SUPPLEMENTARY NOTATION

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Aluminum Replaceable Pad Track (unclassified)
M-1 Aluminum Track (unclassified)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

An aluminum replaceable pad track, capable of utilizing existing T-156 track hardware, was analyzed using both empirical and finite element analyses. The track was to be interchangeable with the current T-156 track at a minimum weight penalty. Such a track was analyzed and its load carrying capability in tension and torsional loads were predicted by correlating track load with block stress and comparing that with the strength levels of ingot metallurgy aluminum alloys, and powder metallurgy aluminum alloys. The former offering the best combination of material properties and economics, the latter offering the best combination of metal strength, ductility, and toughness.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL John Flynn - TACOM, Warren, MI	22b. TELEPHONE (Include Area Code) 574-5070 / 22c. OFFICE SYMBOL AMSTA - RTT

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Table of Contents

LIST OF FIGURES

List of References

Reference	Title	Page
1	3-D Finite Element Analysis of an Aluminum M-1 Tank Track Shoe. Robert S. Joseph and Edward M. Long. 1985 November, for Aluminum Co. of America.	Appendix A
2	"Chrysler XM1 Tank Track Shoe, XM67059 Summary of Inspection After Vehicle Test" C.J. Stefaniak, T.W. Thoburn and H.W. Van Camp 1978 Oct. 09.	None, Ref. only
3	"Forged Aluminum Track Development for U.S. Marine Corps LVTP7 Improved Aluminum Tack Program", J.R. Long, Aluminum Co. of America, for David W. Taylor Naval Ship R&D Center, 1983 June 10. Contract No. N00167-707-C-0217.	None, Ref. only

1.0. INTRODUCTION

1.1. Original Scope of Work

This final technical report prepared by the Aluminum Company of America, Forging Division, for the U.S. Army Tank Automotive Command under contract number DAAE07-84-C-R054, describes phase I in the evaluation of an aluminum replaceable pad track for the M-1 Main Battle Tank. Phase I was to include design evaluation through the use of engineering formulas, stress analysis, weight analysis and Stress Coat/strain gage analysis. Upon completion of this work, a limited number of track shoes were to be submitted to TACOM for laboratory analysis. A second phase was to produce track for field testing on M-1 Main Battle Tanks.

1.2. Work Completed

Only the engineering analysis portion of Phase I was completed. No track blocks were actually produced due to changes in M-1 Tank track philosophies by the U.S. Army.

1.3. Purpose

The integral pad T-156 used on the M-1 tank, though structurally efficient was useless after only several hundred miles of driving due to road pad failure. A replaceable pad track would extend track life by:

- Having thin road pads that would minimize heat build-up due to high internal friction in rubber pads.
- Having the capability to run on bare blocks even if road pad rubber failed.

The purpose of the work was to analyze track shoe block stresses and determine if aluminum could be used as the block material to help minimize weight.

1.4. Previous Work

Although aluminum track had been designed for the M-1 Tank in its development stages, designs were not optimized. Further, earlier aluminum track designs did not use advanced metallurgy alloys that offer significant property advantages.

1.5. Goals

Once the track design was evaluated the contractor was to recommend any relevant design changes and select alloy(s) that would offer the appropriate combination of material properties to best serve the needs of the M-1 Tank.

2.0. OBJECTIVES

The purpose was to design an aluminum replaceable pad (RP) track suitable for service on the M-1 Main Battle Tank. The track was to have the following characteristics:

- Replaceable road pads.
- Integral grousers.
- Be a substitutes for the T-156 track.
- Use the same drive sprockets, bushings, center guides, end connectors, drive pins as the T-156 track.
- Weigh no more than 9615 lbs./vehicle (approximately 800 lbs. more than the T-156 track).
- Utilize the best ingot metallurgy or powder metallurgy aluminum alloys.
- Be of lower life cycle cost than the T-156 track.

3.0. CONCLUSIONS

3.1. <u>Empirical Analysis</u>

The results of the experimental work are summarized on the three plots, Figures 5-9, 5-10 and 5-11, relating material stress to load. The tension plot in particular shows the load carrying abilities of the existing shoe design at the two highest stressed points, Gages four and six (Figure 5-2). The typical ultimate strength levels of several candidate alloys have been superimposed on the material stress vs load for tensile load case. The plot has been extrapolated assuming the loading would remain in the elastic region. Typical ultimate strengths are higher than guaranteed minima for the alloys presented, but are more representative of actual track behavior. These values were used because they best describe the ultimate strength of the material used in previous work by TACOM and others. The results of previous work can be directly compared with those achieved in this analysis.

When the typical ultimate strength of 2014-T6 (70 ksi) is placed on the material stress vs load graph for tensile loading, as seen from Figure 5-9, the track should show catastrophic failure at approximately 185,000 lbs. load. The U.S. Army Tank Automotive Command (TACOM) has analyzed the same track and alloy, 2014-T6, in tension and achieved similar results. When considering other alloy candidates of both ingot and powder metallurgy, materials reviewed not only must have high strength, but also excellent ductility,

toughness and resistance to stress corrosion cracking. This combination of properties implies superior damage tolerance and therefore, battlefield survivability.

3.2. Finite Element Analysis

The FE model results and conclusions are well documented in report #1. Three important points in that report need to be highlighted:

- The rubber bushing preload has a significant effect on the aluminum shoe stresses. When the rubber preload is exceeded or separation occurs, the shoe stresses are higher than they would be if adequate preload were maintained.

- A careful examination of the machine dynamics should be done. This would allow the FE model to be used to its fullest extent. Presently, without accurate boundary conditions, the FE model can only be used for comparison studies.

- Photographs of the photos of the failures enclosed in Report #2, reveal several failures at the three o'clock position or at the parting line of the binocular. This contradicts both the experimental and analytical analyses which indicates that failure should occur at Gage Six (one o'clock) or the Gage Four (fillet radii blending the end plate into the binocular tube) location in a pure tensile load case. The highest stressed area of binocular section is at approximately at one o'clock (see Report #1). Both the in-service dynamic loading and hardware behavior noted above could explain the difference in failure location between that found in field trials and that identified by the laboratory and FE analyses. Further, the effect of parting line location on the shoe block probably contributed to the three o'clock location of the previous track shoe failure described above.

3.3. Suitability of Aluminum

Figures 5-9, 5-10, and 5-11 show that significant increases in load capability of aluminum were possible by using track made of 7050-T74 or 7175-T74 material. Since the powder metallurgy alloys 7090, 7091, and CW67 did not become commercially available they should not be considered. The best alloy/temper candidate is 7175-T74. Further, if track design were not restricted to using T-156 hardware and drive arrangement, a track can be designed to more efficiently use aluminum yielding a lightweight durable track. With the design restrictions applied an aluminum track could be designed that weighs about

9,200 lbs. or only 400 lbs. heavier than the T-156 track.

4.0. RECOMMENDATIONS

4.1. Existing Design Envelope

Due to the original scope constraints of using existing hardware and maintaining the existing envelop, redesign options of the block were somewhat limited. However, based on the work performed, the following areas should be changed to improve the load carrying abilities of the shoe, particularly in pure tension.

- Both analyses show the thin end plate of the shoe is a highly stressed area at Gage Six (see Figure 5-2). This section should be thickened to match the other side.

- The fillet radii between the binocular and the thick end plate Gage Four (Figure 5-2) should be increased. This area has high tension and torsion stresses.

- Change the material alloy to 7050-T74 or 7175-T74 to increase the overall load carrying abilities of the shoe.

- Determine if additional rubber bushing preload is required.

The above listing is not all inclusive since the effort to correlate the field failures to the analysis was not conclusive. A complete optimization design is not possible since a better definition of the loads which caused the track failures is required.

4.2. Connecting Hardware

A detailed study of the load carrying capabilities of the shaft and end connectors should be done. One theory of possible early track failures is that an end connector actually fails first, thus drastically changing the load path and causing high point loading where rubber prestresses are exceeded and separation occurs.

4.3. Dynamic Loading

A careful examination of the machine dynamics should be done. This would allow the finite element model generated to be used to its fullest extent. Understanding these machine dynamics will help to correlate both FE as well as analytical experimental data with actual track service loading. This may ultimately have an effect on design as well as alloy.

4.4. Unrestricted Design

If the design were not restricted to utilizing the T-156 hardware, then an aluminum track could be optimized to work on the M-1 Tank and survive the dynamic loading and severe service requirements of the vehicle. This might ultimately require different hardware and drive sprockets than the T-156 track. However, this would assure a lightweight replaceable pad track that would satisfy the service requirements of the M-1 Tank.

5.0. DISCUSSION

5.1. Background

The M-1 Main Battle Tank, due to its weight and high performance characteristics places severe demands on its track. The T-156 track currently installed on the M-1 Tank has an integral road pad bonded to a steel framework. Due to the high loads the road pads must withstand, heat readily builds up in the road pad from internal friction. This combined with dynamic loads destroys the road pads. Because the metal framework bonded to the road pad does not provide a good tractive surface, when the bonded rubber pad deteriorates the remaining bare steel block presents an inadequate running surface for the tank.

A replaceable pad (RP) track allows the road pad to deteriorate without, due to block design, inhibiting tank mobility. Steel RP tracks have been considered for the M-1 Tank, but due to their solid block design require a severe weight penalty. By substituting aluminum for steel the block weight is significantly reduced. As a result an aluminum RP track can provide RP track benefits at a weight comparable to the weight efficient T-156 track.

5.2. Previous Aluminum Track Programs

Alcoa designed an aluminum RP track for the M-60 Tank to the T-142 design. This track was quite successful in testing at the Aberdeen Proving Grounds yielding track lives up to 8,000 miles. Also, aluminum RP track proved successful in lighter amphibious vehicle testing. An aluminum track design existed for the M-1 Tank. This design was part of the early development work on the M-1 by General Motors and Chrysler Defense (now part of General Dynamics). This track had limited success due to other vehicle drive problems and was dropped. The original track used alloy 2014-T6, a relatively high strength material.

The U.S. Army Tank Automotive Command had also done some laboratory analysis on this original M-1 aluminum track. This work concluded, among other things, that the tracks ultimate

tension load capability was about 185,000 pounds. That information was useful in the work of this report.

5.3. Laboratory Analysis

The objective of the analysis was to determine the load capabilities of a track shoe block and recommend possible improvements. Initially an experimental approach was pursued with the expectation of correlating the findings with actual field failures. This, however, was not conclusive, so a finite element analysis was done. It also did not agree entirely with field failures, but was in fair agreement with the experimental work.

In both analyses, the rubber pads on both faces of the block were not accounted for, since they add little structurally. The rubber bushings between the shaft and the block, however, were considered.

In Phase I, several track shoes were forged in alloy 6061-T6 and were then fitted with the standard T-156 hardware excluding pads and road wheel rubber. These parts were then subjected to a Stress Coat/Strain Gage (SC/SG) analysis to locate and quantify the high stress areas in the block. This method locates stresses in parts by first coating them with a brittle lacquer material and then subjecting them to a load. As the load is increased, the more highly stressed areas in the part begin to elongate first cracking the brittle lacquer coating. The cracked coating located the highly stressed areas which were then fitted with strain gages. With the strain gages in place, the part was placed under load again and the strain was measured. The measurements taken were converted into stress levels in the part. By monitoring the strains (and consequently the stresses) generated for given loads, a curve was set up to correlate track tension and torsion to parts stressed.

For this SC/SG analysis, the shoes were placed in a special track stressing fixture (shown in Figure 5-1) that tests three pitches, connected together, that applies tension and torsion loads both separately and in combination. This fixture was specifically designed to simulate track load and loading geometry. The shoes of the middle pitch were evaluated to minimize any end effects of the test setup.

Following the SC/SG analysis, computer modeling of the track using Finite Element (FE) analysis was done to completely understand the load/stress relationship in the track. The procedure for this work and the results there found are explained in detail below.

Once the track load/material stress relationship was estab-

Figure 5-1 Test Fixture

lished, track tension and torsional load abilities were predicted based on the ultimate strengths of several candidate alloys. The results of this correlation are shown in Figure 5-9. Based partially on this prediction of track load capability, alloys were recommended. Other factors considered in the recommendation included stress corrosion cracking resistance, ductility, forgeability and toughness. The alloy selections are stated in RECOMMENDATIONS 4.0.

5.3.1. Experimental Analysis. The experimental portion included both Stress Coat and strain gage evaluation. The Stress Coat was applied to a block installed in the test fixture (see Figure 5-1) and then subjected to a tensile load. The high stress areas and direction of stress lines were noted. The block assembly was then loaded in torsion. The high stress areas and directions were again noted. (See Figures 5-2 and 5-3) From this information, the location and orientation of six single gages was determined. One rosette gage, Gage Seven, was also applied to confirm the method of gage orientation of the six single gages to the principal axes. (See Figure 5-3) The block assembly was installed in the test fixture and subjected to the following load cases:

1. Pure tension

2. Pure torsion

3. Combination tension/torsion
   (20,000 lbs. tension and varying torsion)

4. Combination tension/torsion
   (50,000 lbs. tension and varying torsion)

Figures 5-4, 5-5, 5-6 and 5-7 are plots of the test load vs strain for the above load cases. As can be seen from the plots, Gages Four and Six are of primary concern since they are the maxima.

Next a plot of material stress vs load on Gages Four and Six was generated for the tensile case. (See Figure 5-9) Superimposed on this plot were typical ultimate strengths of various alloys and the corresponding load necessary to achieve those strength levels. For all alloys shown, a modulus of elasticity of 10E6 psi was assumed. Similar graphs were created for the pure torsion load case (Figure 5-10) and the combined tension (50,000 lbs.) and torsion case (Figure 5-11).

5.3.2. Analytical. Since the experimental stress result did not appear to agree with in-service failures previously reported (Report 2), an analytical approach was used to better understand the entire load distribution within the block. The stress pattern on the inside of the binocular was of particu-

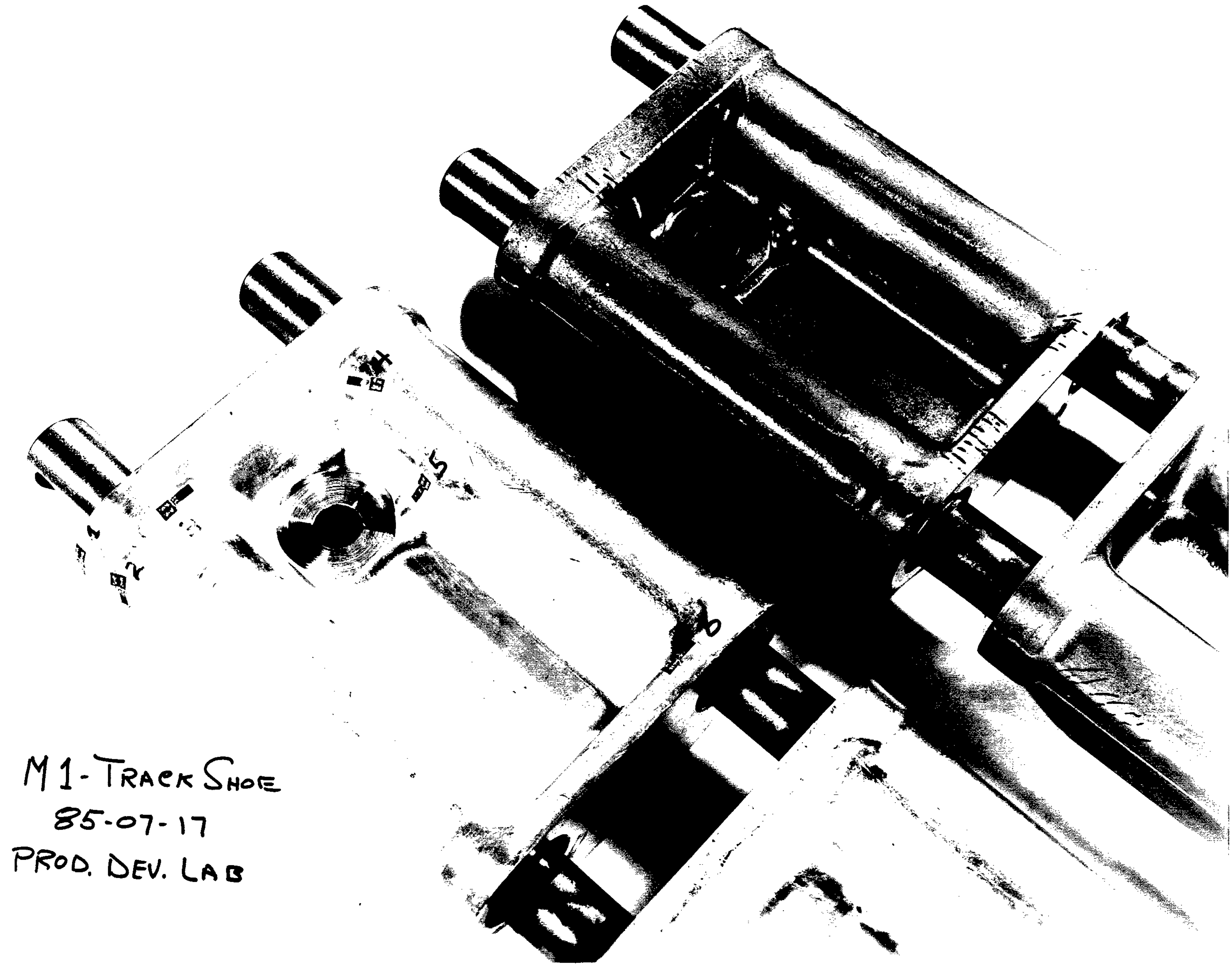


Figure 5-2 Stress Coat Results
And Strain Gage Locations

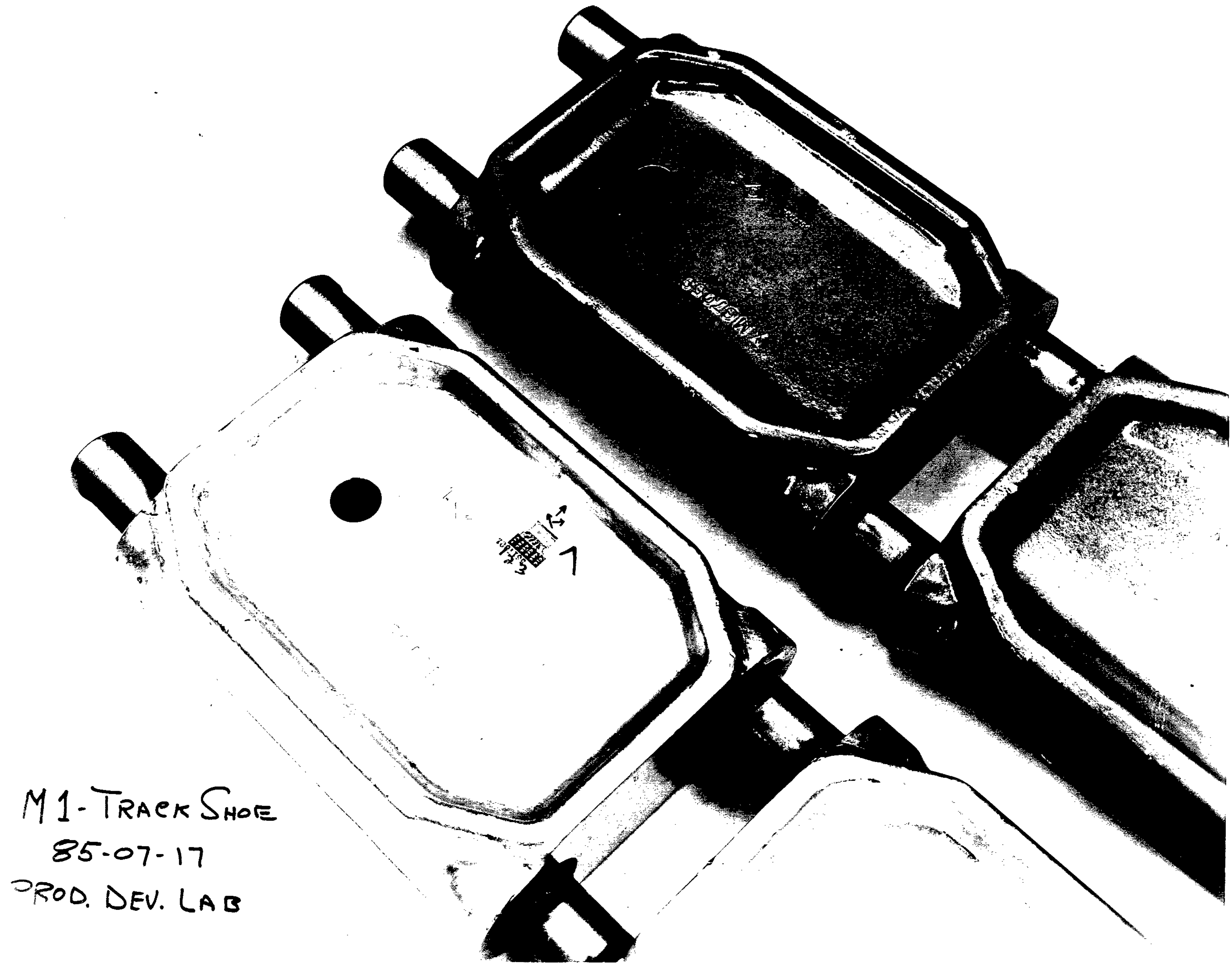
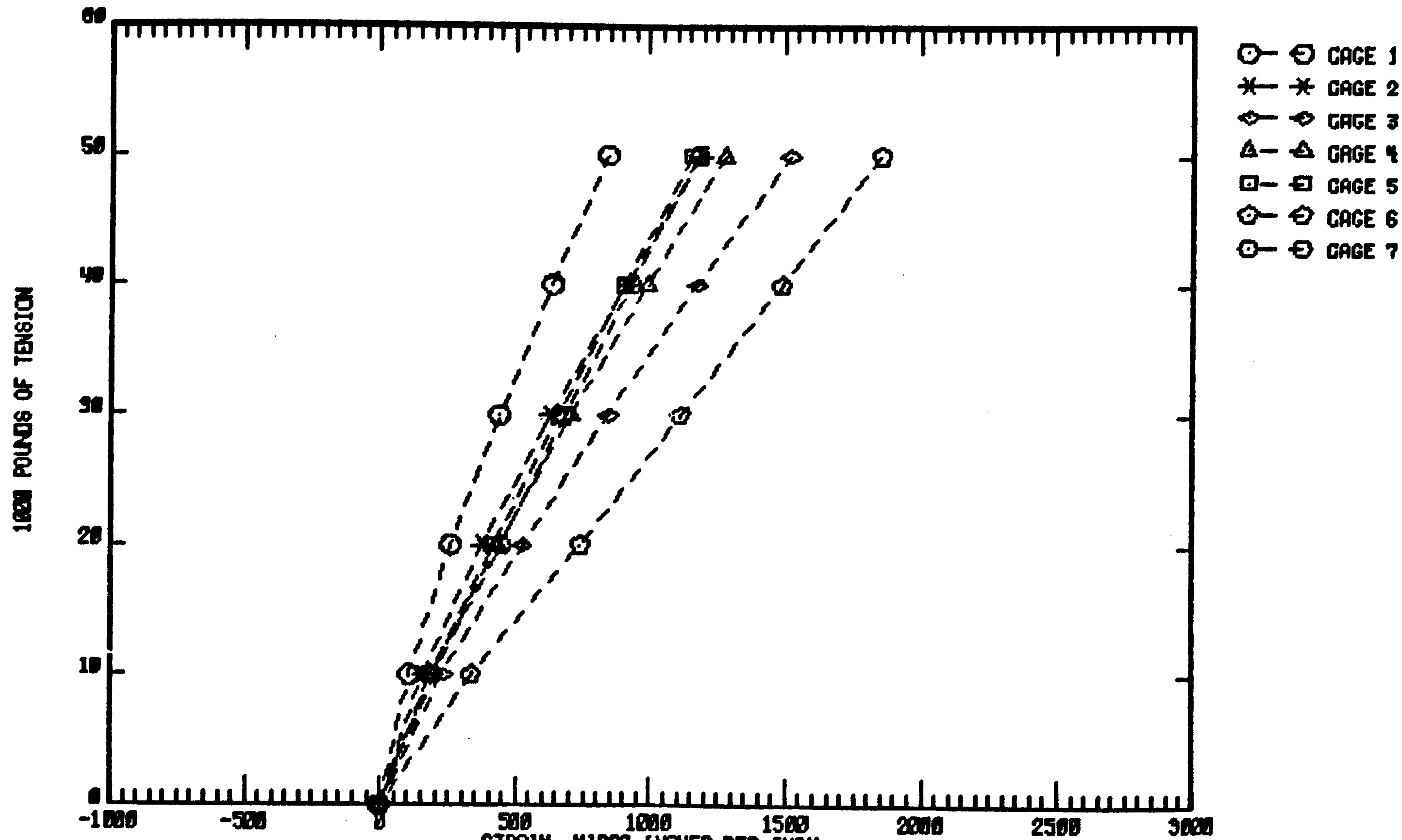
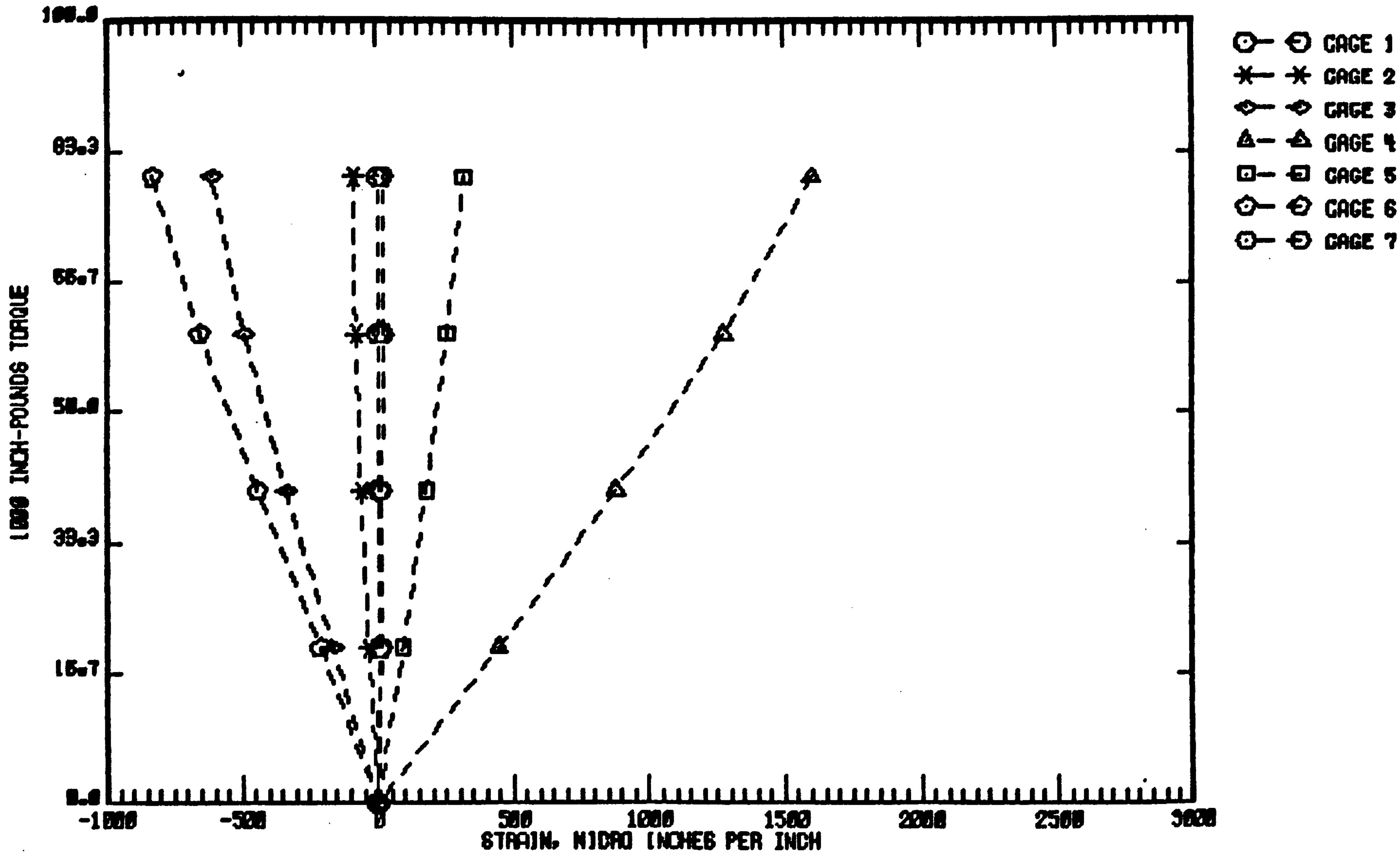


Figure 5-3 Stress Coat Resluts
And Strain Gage Location



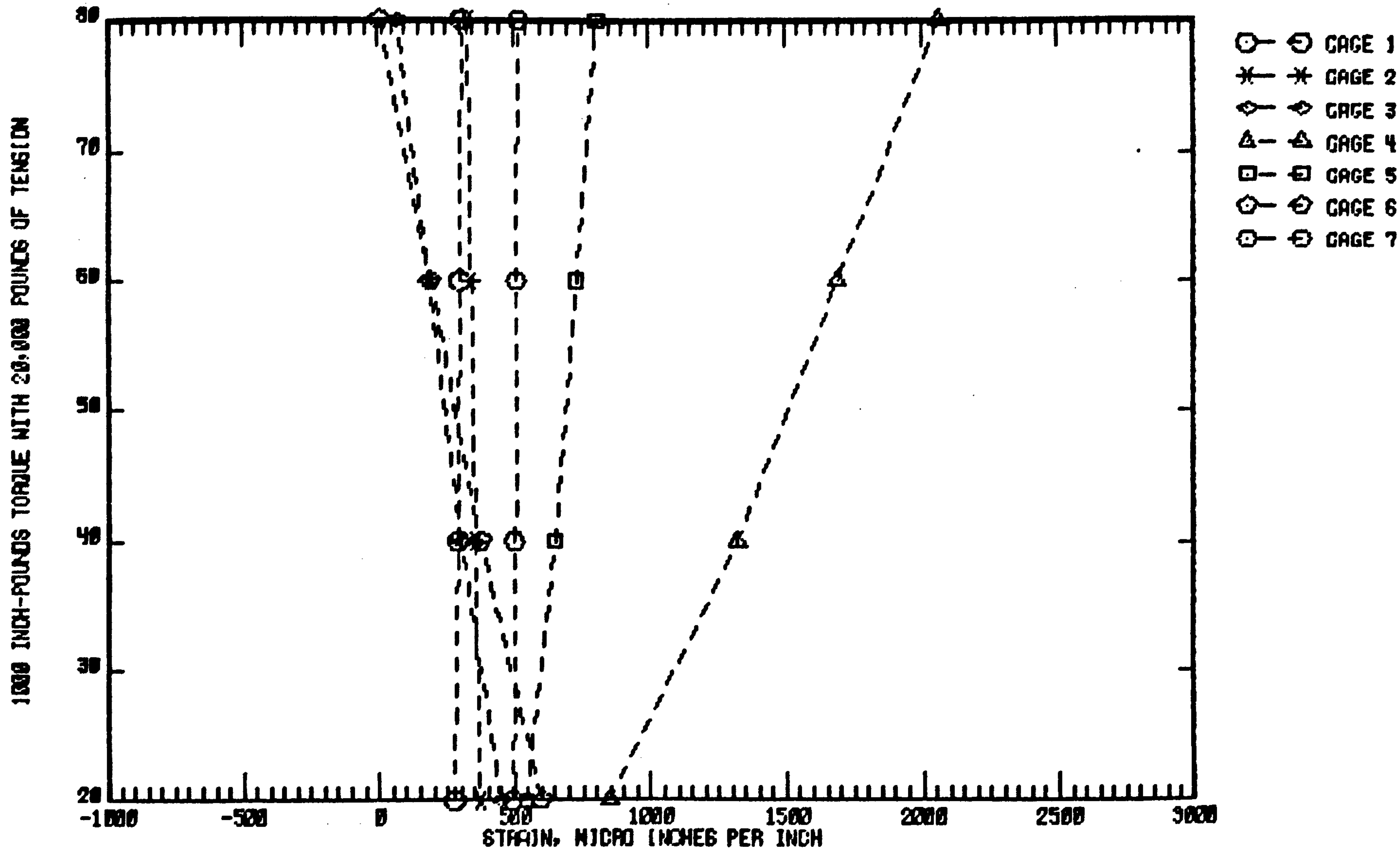
SIMPLE TENSION, STRAIN VS. LOAD

FIGURE 5-4



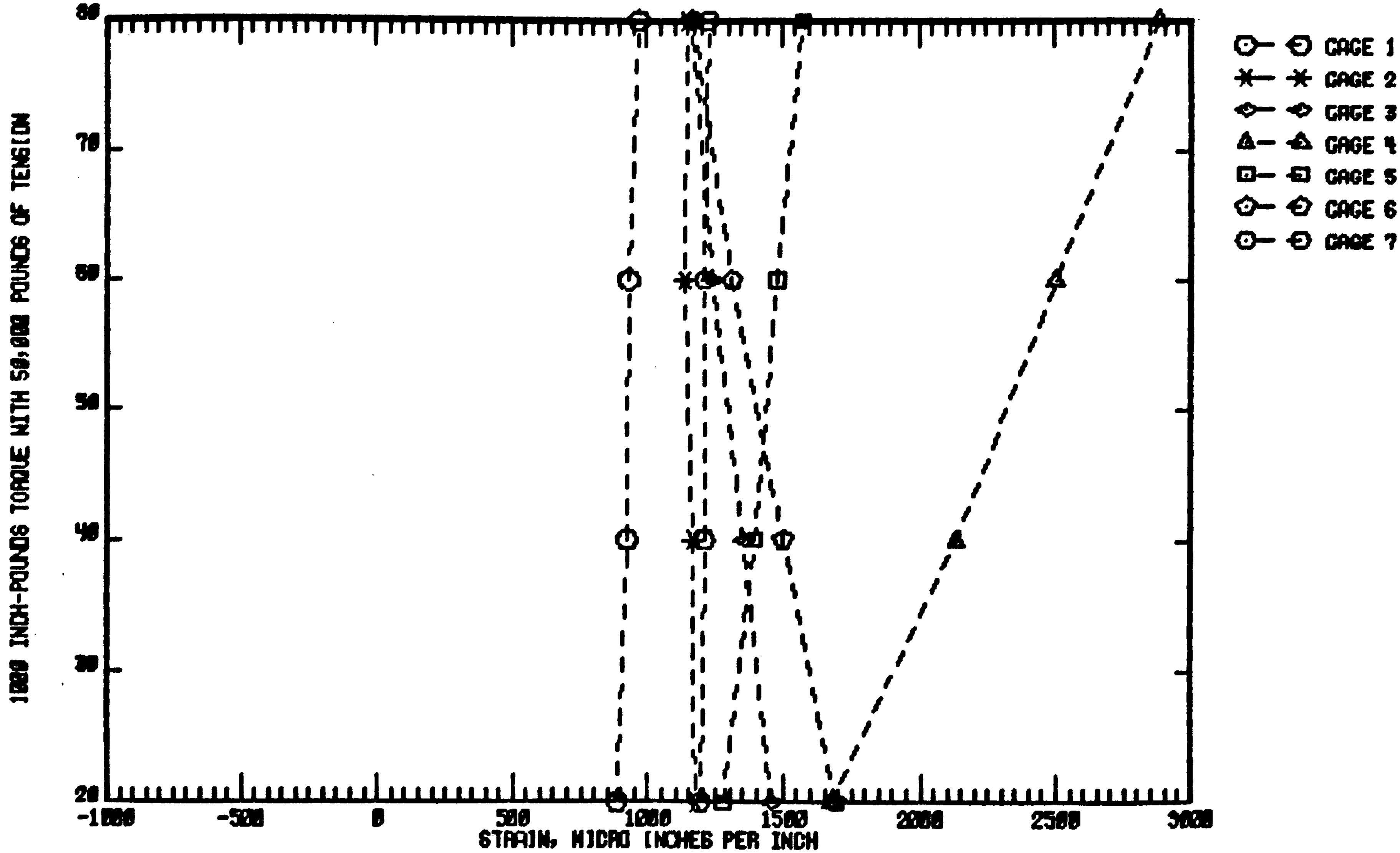
SIMPLE TORSION, STRAIN VS. TORQUE

<u>FIGURE 5-5</u>



COMB. LOAD, TORQUE AND TENSION, STRAIN VS. LOAD
20,000 POUNDS TENSION

FIGURE 5-6



COMB. LOAD, TORQUE AND TENSION, STRAIN VS. LOADS
50,000 POUNDS TENSION

FIGURE 5-7

lar interest since strain gages could not be applied in this area. Finite Element (FE) analysis was chosen as the best approach to analyze the shoe. Because of the symmetry of the track shoe assembly, only ½ of a block was modeled. (See Figure 5-8) The model was subjected to the following load cases:

1. Tensile load

2. Out of plane load

3. Twisting load

Checks were then done to compare analytical to experimental results. In general, the model corresponds with the experimental results. The FE model confirmed peak stress locations on the shoe. However, the experimental and analytical results did not agree very well with the failures photographed in Report #2.

The details of the model are covered in greater depth in report entitled: "3-D Finite Element Analysis of an Aluminum M-1 Tank Track Shoe" (Report #1).

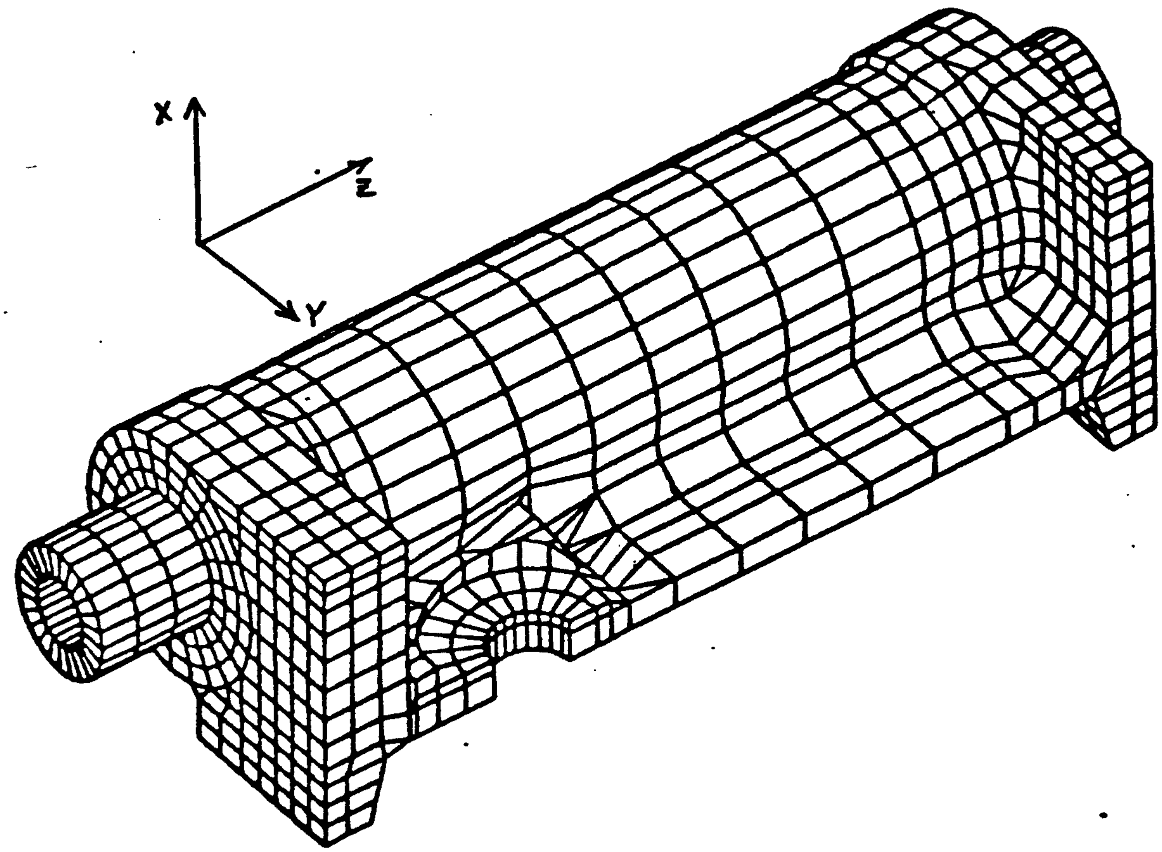
5.4. Material Selection

For the purpose of the experimental analysis, aluminum alloy 6061-T6 was used since it is easy to forge, machine, and use in Stress Coat/strain gage analysis. The material does not have sufficient properties for service on the M-1 Tank, although it proved quite successful in testing on a P-7 Program (Report 3). The analytical analysis combined with this laboratory work and work by TACOM led to Figures 5-9, 5-10, and 5-11 which compare material stress at given loads for higher strength aluminum alloys that could be used in aluminum track. As these figures show, high strength 7XXX alloys far surpass the load carrying capability of alloy 2014-T6.

Since powder metallurgy alloys 7090, 7091, and CW67 (a 7091 derivative) were not commercialized they were dropped from consideration. Alloys 7050-T74 and 7175-T74 are commercially available and should offer good candidates for aluminum track material for the M-1. For strength reasons, 7175-T74 would be the best alloy for test purposes.

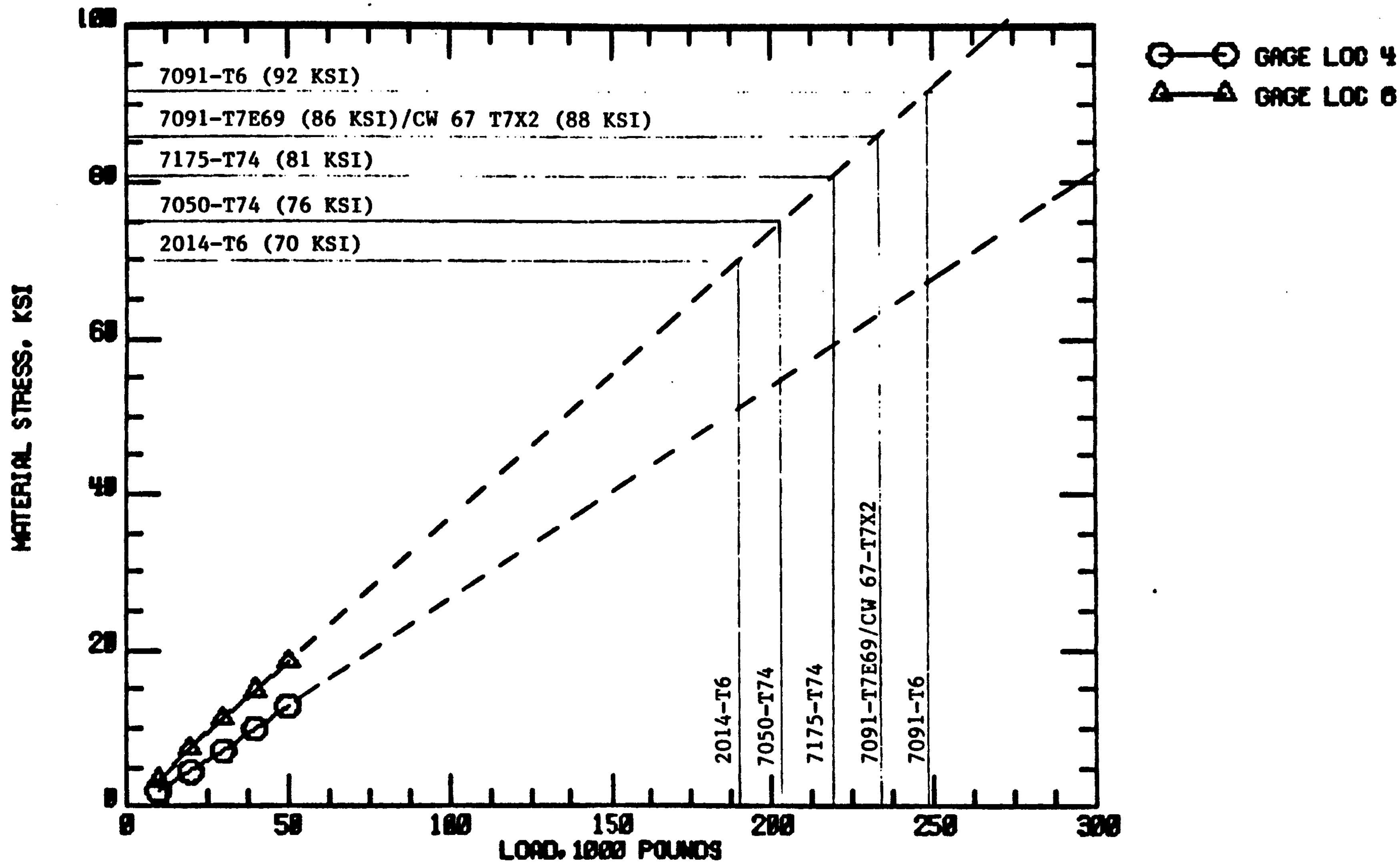
5.5. Second Tier Material Properties

Due to the demanding service conditions of a tank track, any material must combine strength with damage tolerance. The second tier properties of both 7050-T74 and 7175-T74 are excellent. These include ductility and toughness which are both indicators of damage tolerance.



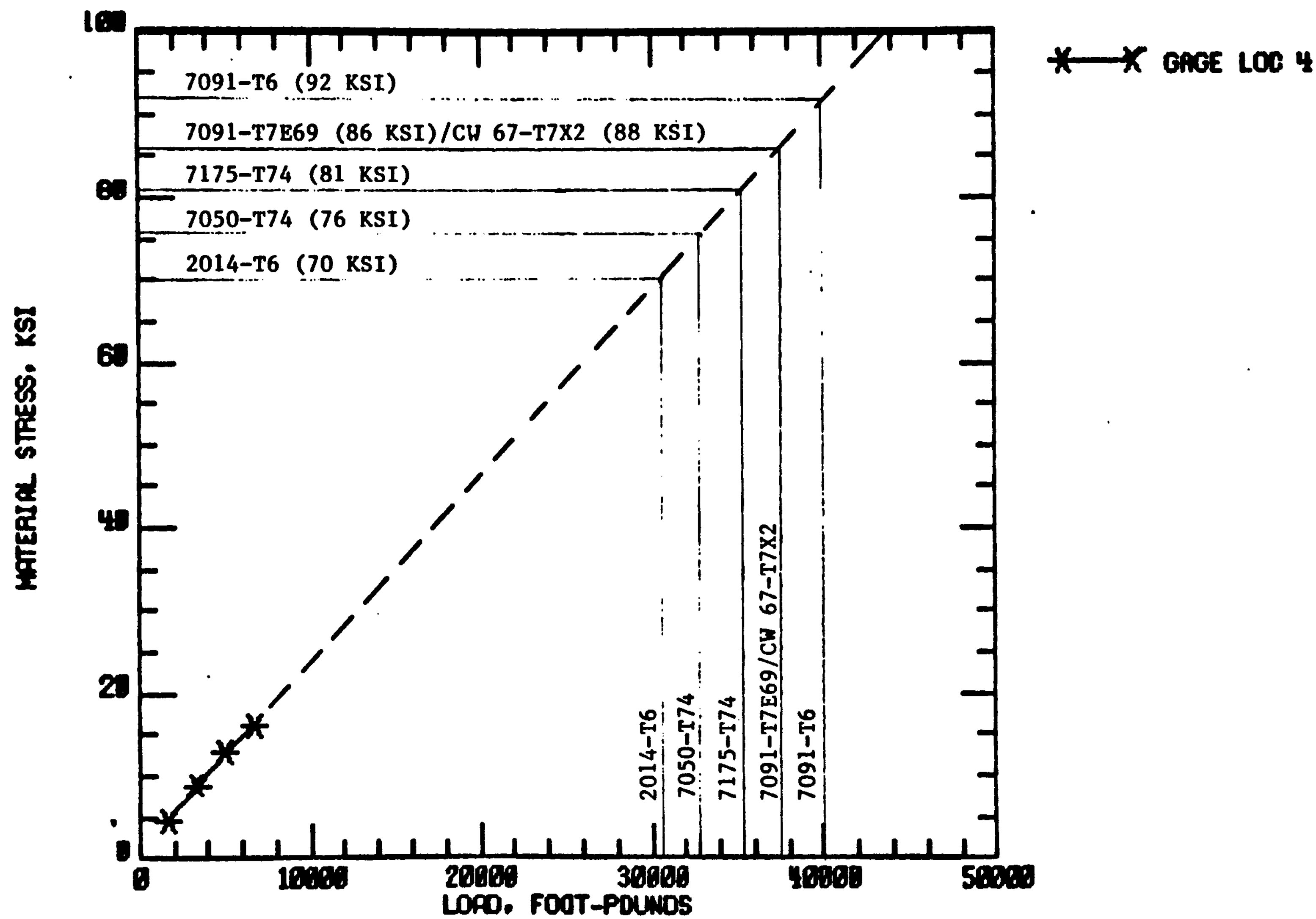
3-D ANSYS Model of M-1 Track Shoe, Isometric View

FIGURE 5-8



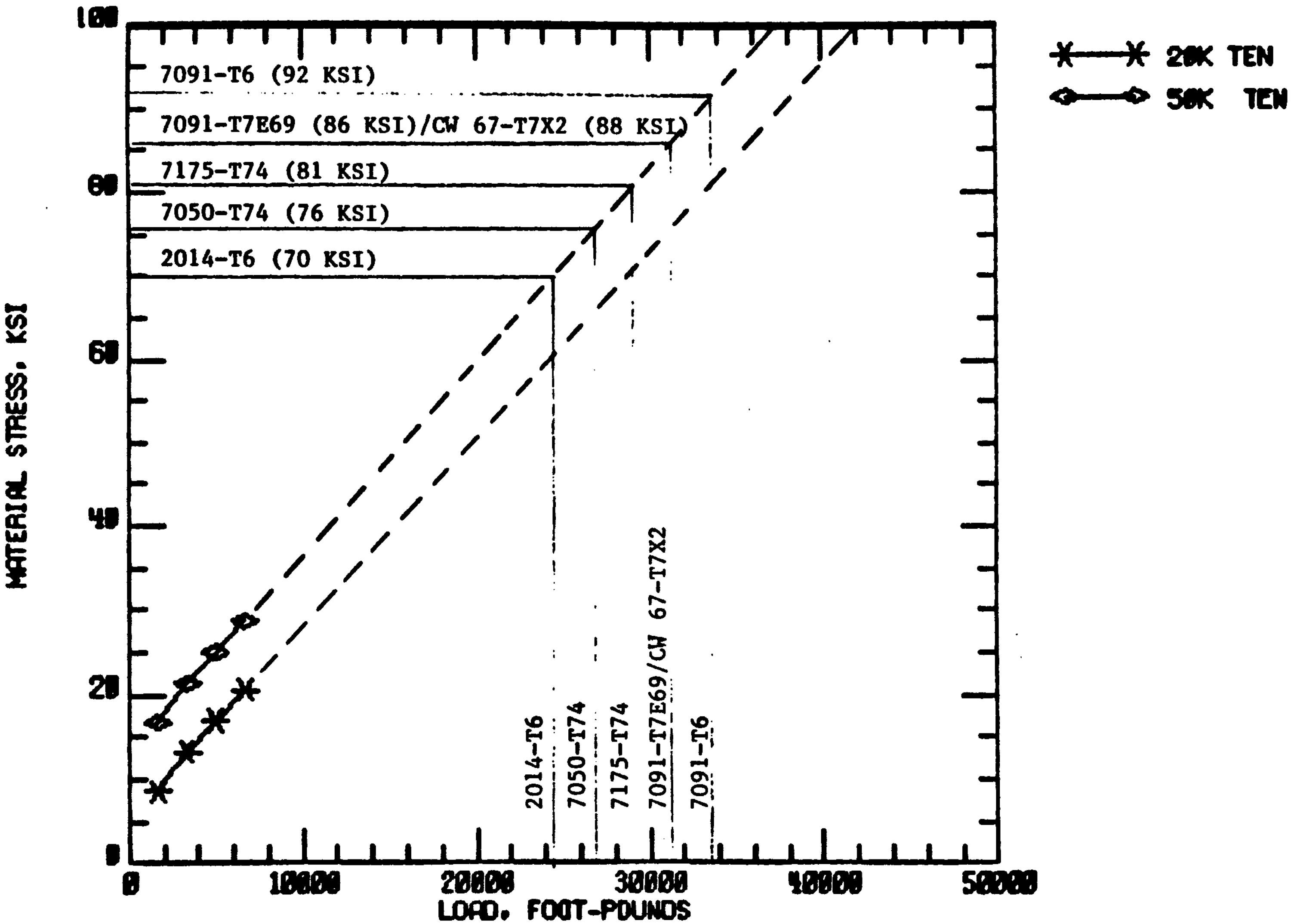
LOAD VS. MATERIAL STRESS FOR PURE TENSION
(ASSUMING A MODULUS OF ELASTICITY OF 10E6)

FIGURE 5-9



LOAD VS. MATERIAL STRESS ~~FOR~~ PURE TORSION (ASSUMING A MODULUS OF ELASTICITY OF 10E6)

FIGURE 5-10



LOAD VS. MATERIAL STRESS FOR COMBINATION LOAD
CONSTANT TENSION AND VARIABLE TORSION FOR GAGE LOCATION 4
(ASSUMING A MODULUS OF ELASTICITY OF 10E6)

FIGURE 5-11

5.6. Weight

Weight calculations indicate that an aluminum RP track of the original design would weigh 9,215 lbs., or only 400 lbs. heavier than the T-156 track. This is well within the weight bogey for an aluminum RP track for the M-1 Tank.

5.7. Design

The design evaluated used the T-156 hardware and drive sprockets so that if an aluminum track proved successful in analysis and lab testing it could be incorporated on the vehicle without requiring unique hardware. This also would ensure a continuous supply of spare parts common to both the aluminum track and the T-156 track. This of course limited design flexibility for the aluminum track. An aluminum track design without these restrictions could be readily optimized using the data collected. This would lead to more efficient aluminum designs for the M-1 Tank that would increase track life with a lightweight track.

Appendix A

DEAC-TR-120

3-D FINITE ELEMENT ANALYSIS OF AN ALUMINUM M-1 TANK TRACK SHOE

Prepared For

Aluminum Company of America
1600 Harvard Avenue
Cleveland, OH 44105

Prepared By Robert S. Joseph
Robert S. Joseph

Edward N. Long
Edward N. Long

November 1985

TABLE OF CONTENTS

1.0 SUMMARY

This report documents the finite element analyses that are performed on the aluminum M-1 tank track shoe using the ANSYS finite element computer program (Revision 4.1). The scope of work defined for this project by Alcoa is contained in Appendix A of this report for reference. The purpose of this project is to develop a three-dimensional finite element model of the track shoe including the steel pin and rubber bushing and to demonstrate part performance by analyzing three separate load cases.

Section 2.0 describes the 3-D finite element model of the track shoe that is developed to evaluate the track shoe. The model includes the steel pin and rubber bushing in order to develop the proper loading on the shoe binocular. The model is a one-half symmetry model of the shoe and contains 2838 ANSYS isoparametric solid elements. Detailed descriptions of the various element types and nodal point locations are given in Section 2.0..

Three load cases are analyzed with the 3-D model by applying the appropriate boundary conditions on the two symmetry planes. Sketches illustrating the three load cases, namely, pure tensile load, out-of-plane load, and twisting load, are contained in Section 3.0. The maximum loads assumed for these cases are somewhat arbitrary since the primary purpose of these demonstration runs is to qualify the analytical model. However, the maximum load for the pure tensile load is selected to correspond to the maximum load used in the Goodyear

test (Figure B-5). Additionally, the analytical model is linear and the results can be scaled as long as rubber preload is maintained in the binocular section of the shoe.

The track shoe assembly contains three different materials: the steel shaft, the rubber bushing, and the aluminum shoe body. The aluminum and steel material properties are readily available in the literature and the properties used in this analysis are listed in Section 4.0. However, rubber properties, especially a compressive stress-strain curve, is not easily found. Rubber does not follow Hooke's law and can be characterized by a nonlinear elastic behavior which becomes stiffer with increasing strain. The approach used in this analyses is to select an effective Young's modulus from a rubber stress-strain curve that will approximate the actual rubber stiffness of the assembly. A development of the rubber properties for initial use in the analytical model is presented in Appendix B. These rubber properties are further refined as a result of the tensile load calibration runs discussed in Section 5.2.

A supplemental parametric study using a 2-D interaction model is presented in Appendix C. The purpose of this study is to investigate the interaction of the shaft, rubber, and endplate due to a tensile pull load using an economical model. The sensitivity of the rubber modulus and the effect of rubber preload are investigated. These results were used to guide the 3-D model analysis presented in Section 5.0 and to gain some insight into the load paths of the assembly.

Section 5.0 presents the 3-D finite element stress results for the three demonstration load cases. The results are presented in the form of tabulated maximum stress summaries, displacement plots, and stress contour plots. The results demonstrate that the 3-D track shoe model behaves in a predictable and proper manner for the loads considered. Input listings for all final ANSYS runs discussed in this report are contained in Appendix D. A listing of all computer files for this project residing on Alcoa's DEC VAX 11/785 computer system is given in Section 6.0.

2.0 FINITE ELEMENT MODEL DESCRIPTION

This section describes the 3-D finite element model that was developed to evaluate the M-1 tank track shoe body. The model also includes the steel pin and rubber bushing in order to develop the proper loading on the shoe. Photographs of the track shoe body without pin and bushing are shown in Figures 2-1 and 2-2.

A one-half symmetry model of the track shoe was developed using ANSYS STIF45 isoparametric solid elements. Figures 2-3 through 2-7 show various isometric views of the 3-D finite element model. The model contains a total of 2838 solid elements with a breakdown of the elements as follows:

Component	No. of Elements
Steel Shaft	624
Rubber Bushing	480
Aluminum Shoe	1734

The specific dimensions used to construct this model are defined in Figure 2-8. These dimensions were obtained from drawings supplied by ALCOA and these reference drawings are listed in Figure 2-8. Since the steel shaft extends through a shoe pair, only one-half of the shaft was modeled. The gap between the shoe pair was given as 1.82", and therefore the shaft length on the inboard side was set to 0.91". The shaft extension on the outboard side was set to 1.25" which is the distance to the midpoint of the flat on the shaft.

Although the model is constructed of all solid elements, it was advantageous to separate the model into seven element types in order to facilitate model development and postprocessing of results. Figure 2-9 shows a sketch of the model identifying the various element types. The nodal point numbers for each element type are also listed.

Since the displacement and stress results are calculated and presented at nodal points, it is important to have a complete description of all the nodal points in the model. Figures 2-10 to 2-17 define the nodes in each element type of the model. In general, the model was developed by defining nodes on one plane and then incrementing the nodes in the third direction.

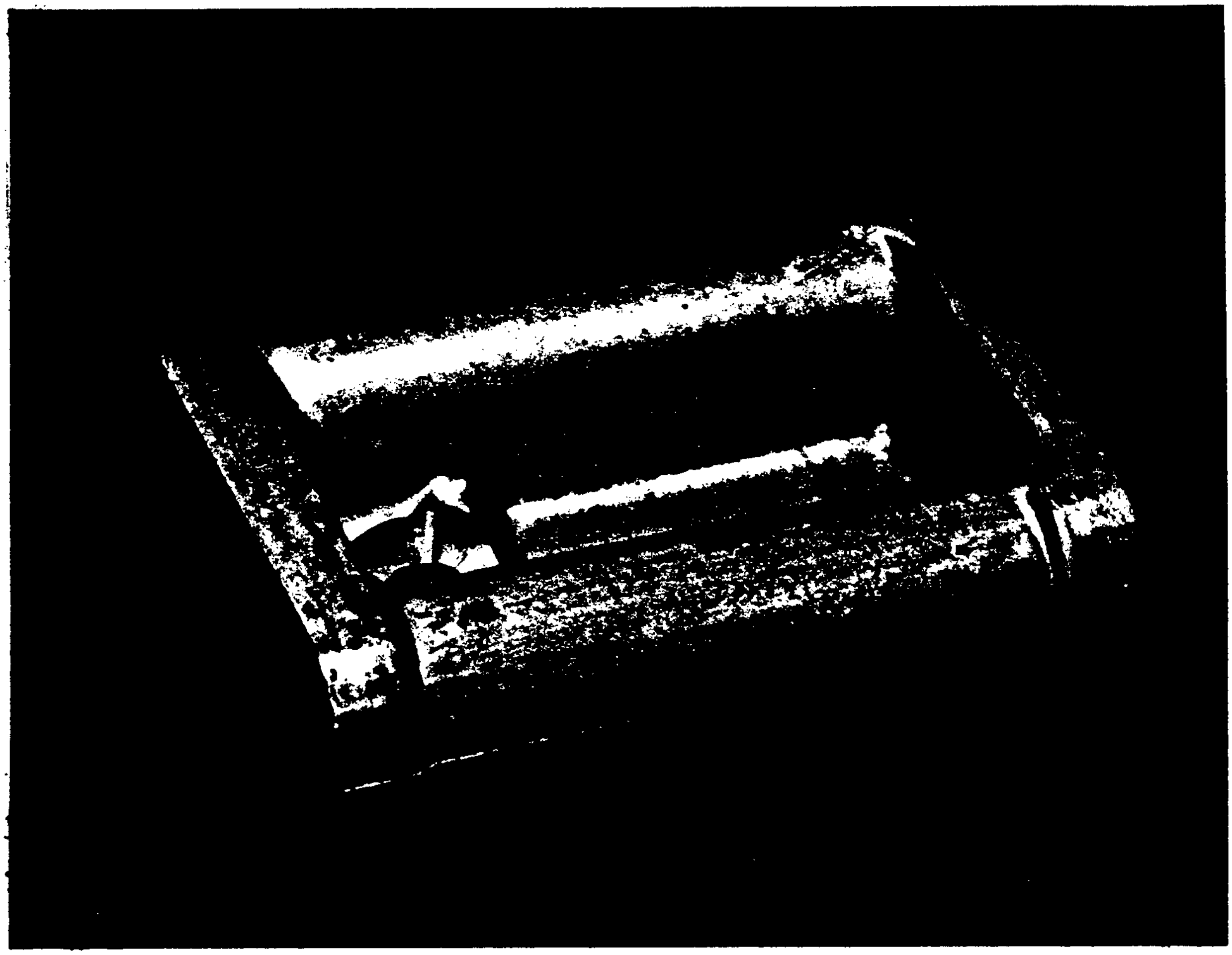


Figure 2-1 - Photograph of an Aluminum M-1 Tank Track Shoe, Top View

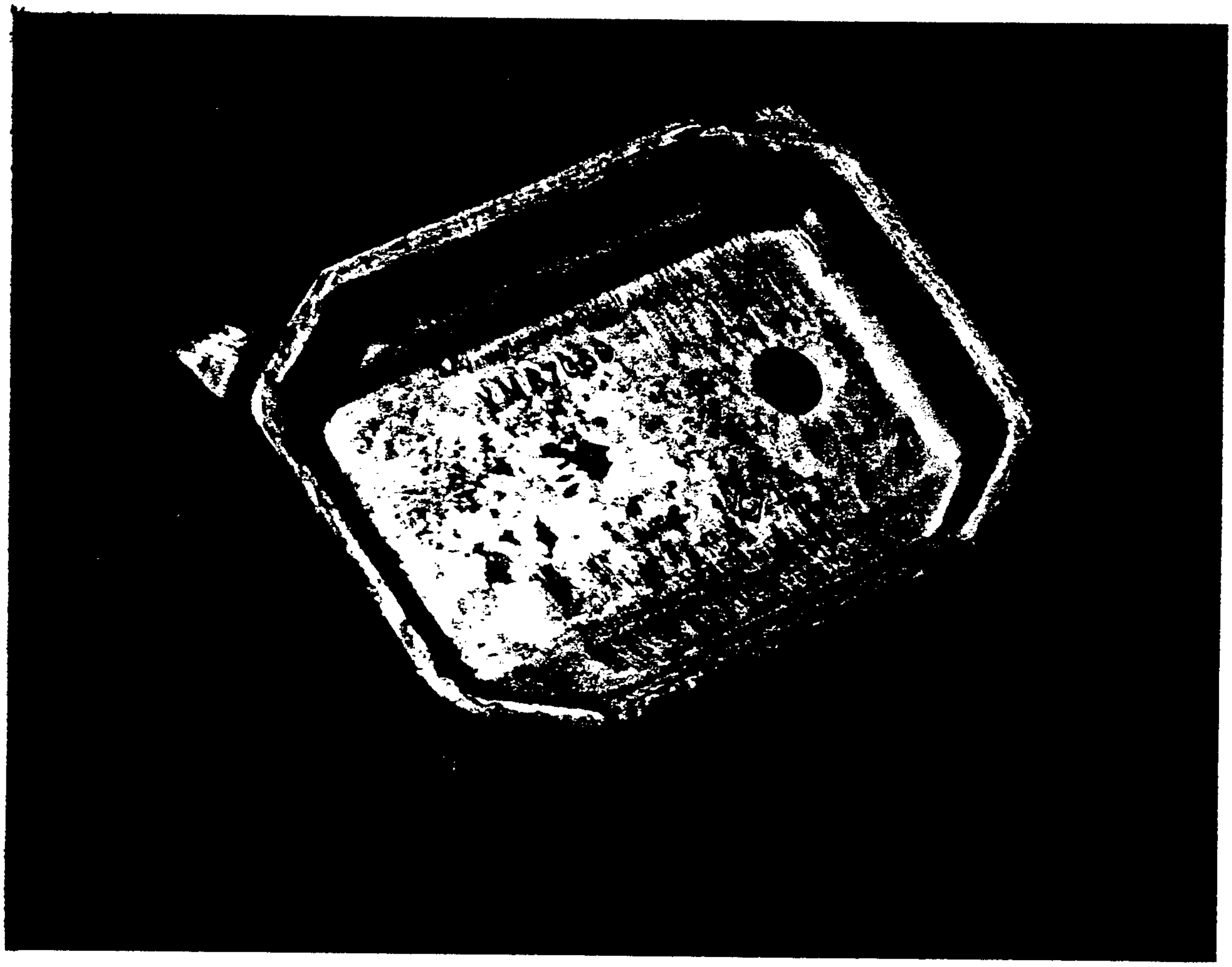
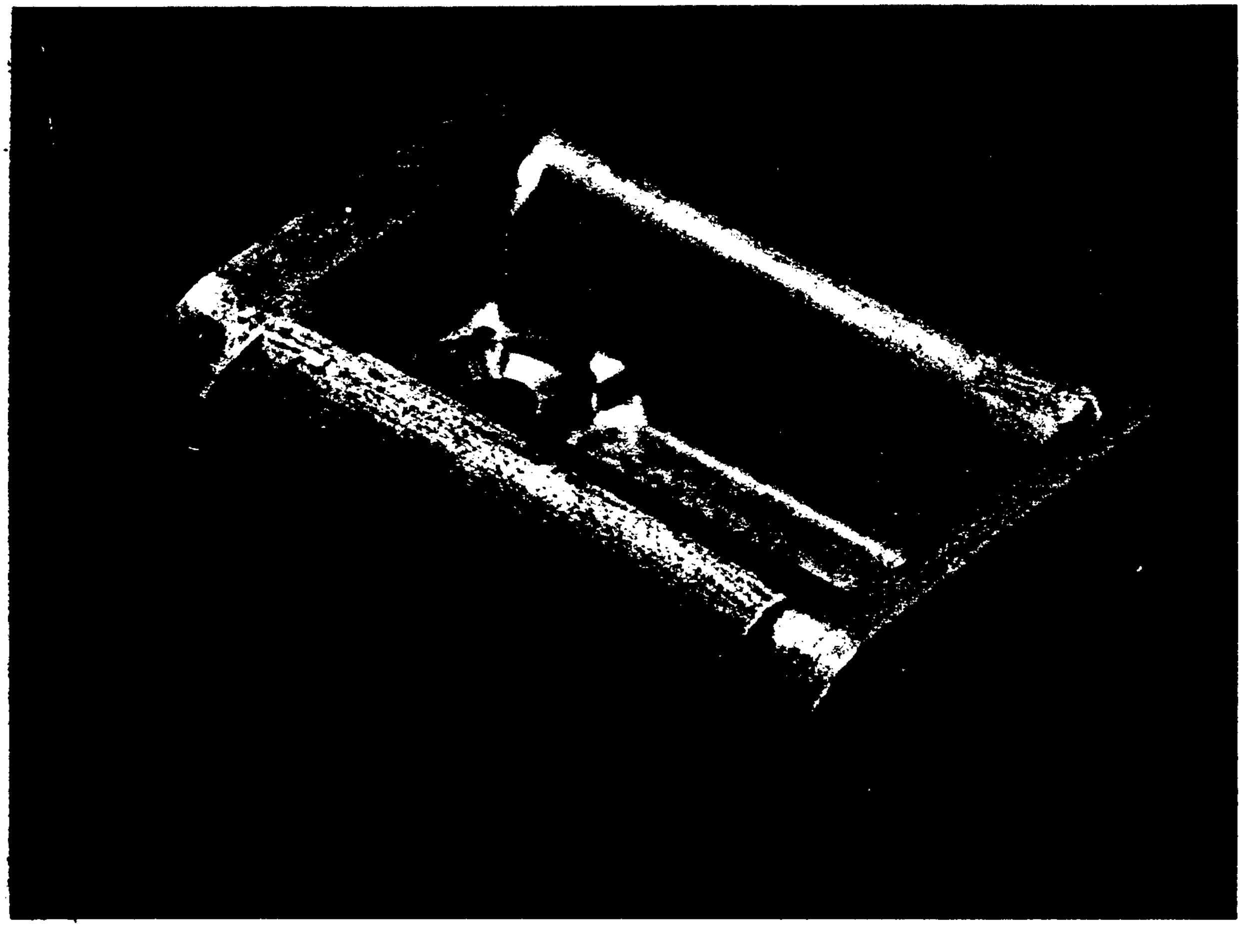


Figure 2-2 - Photograph of an Aluminum M-1 Tank Track Shoe, Bottom View



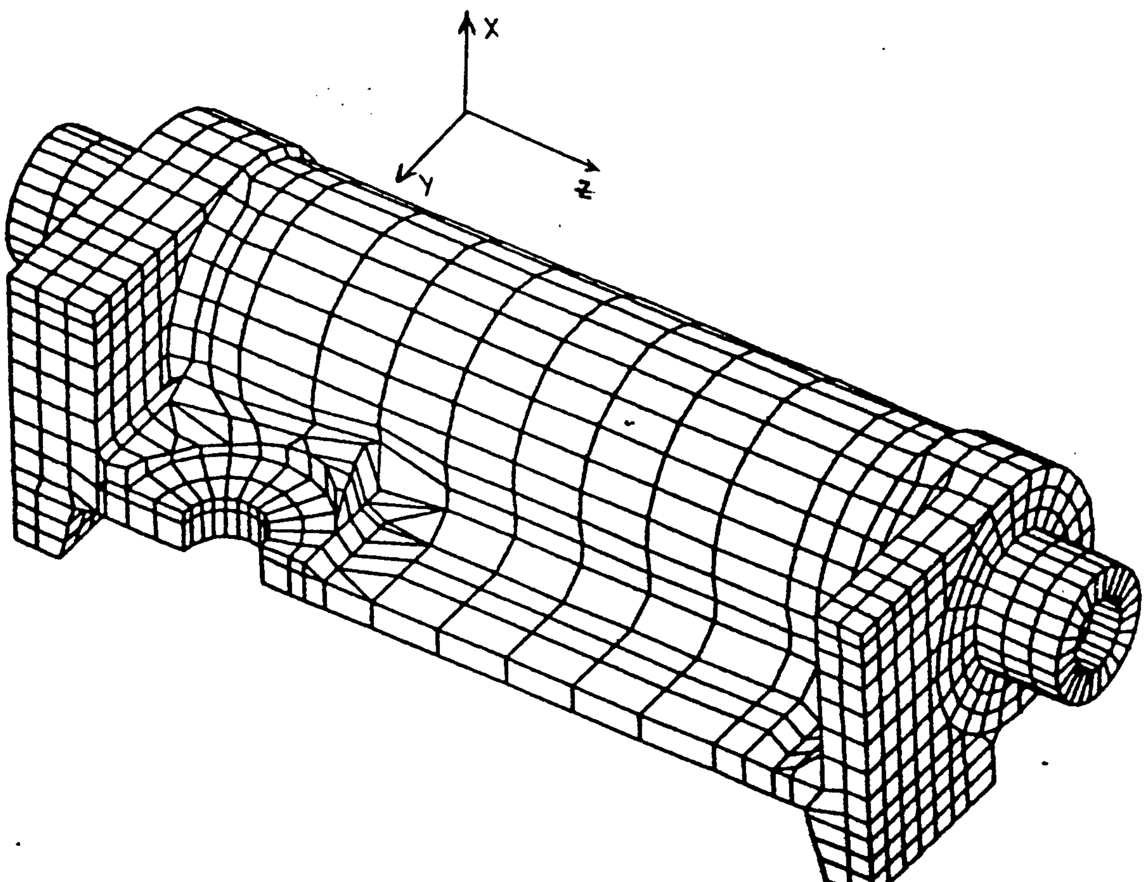


Figure 2-3 - 3-D ANSYS Model of M-1 Track Shoe, Isometric View

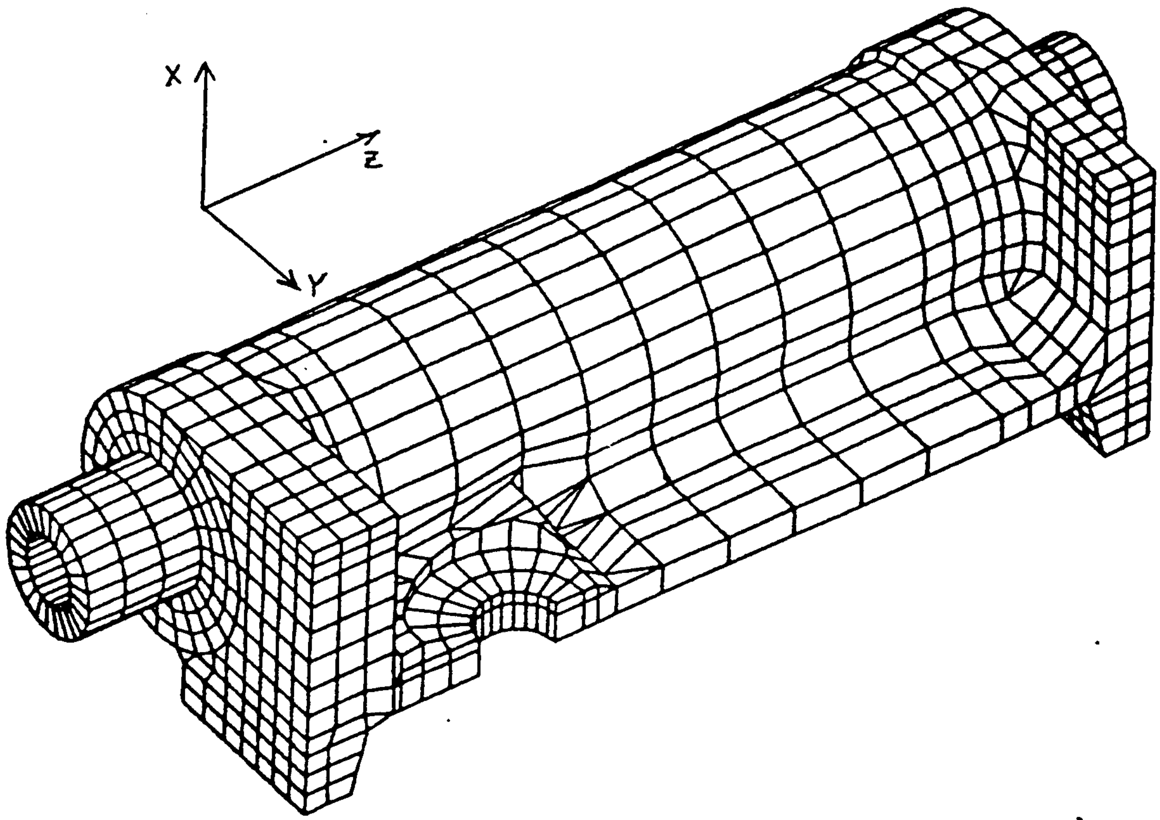


Figure 2-4 - 3-D ANSYS Model of M-1 Track Shoe, Isometric View

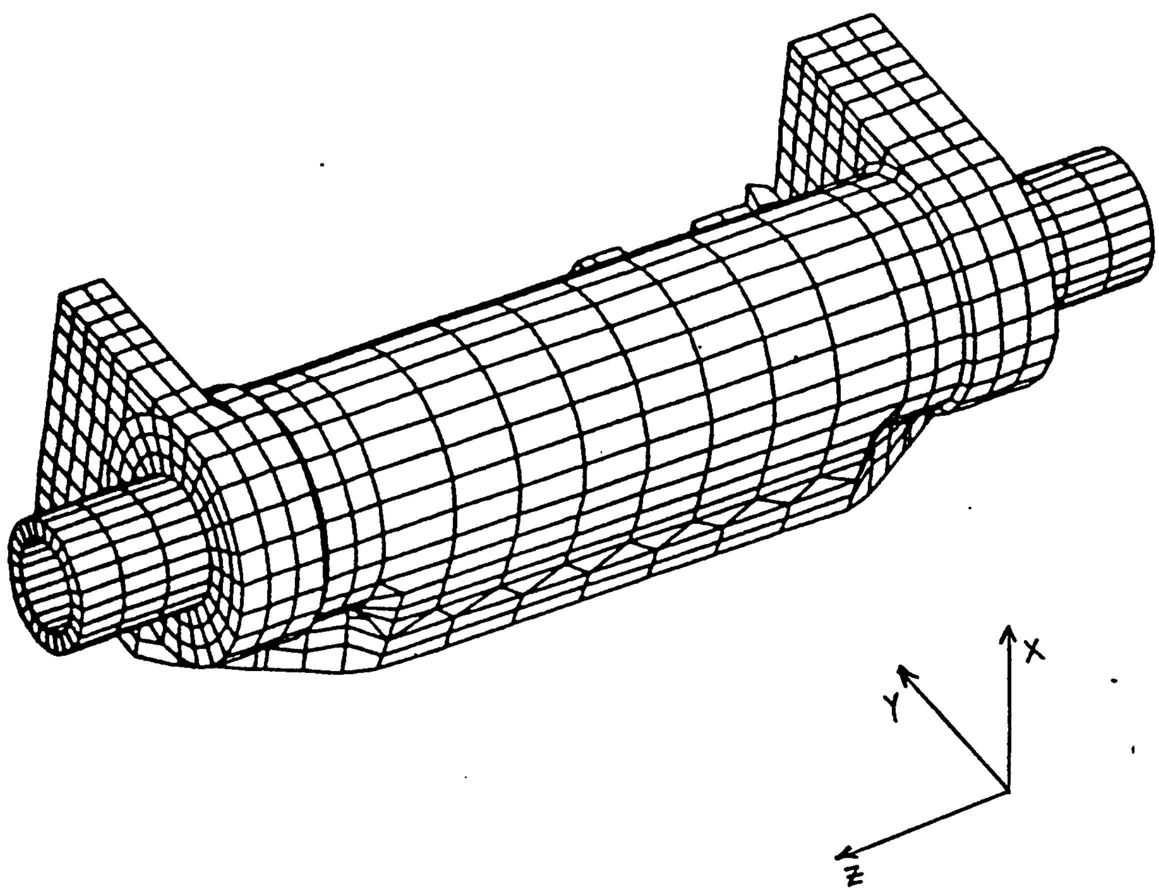


Figure 2-5 - 3-D ANSYS Model of M-1 Track Shoe, Isometric View

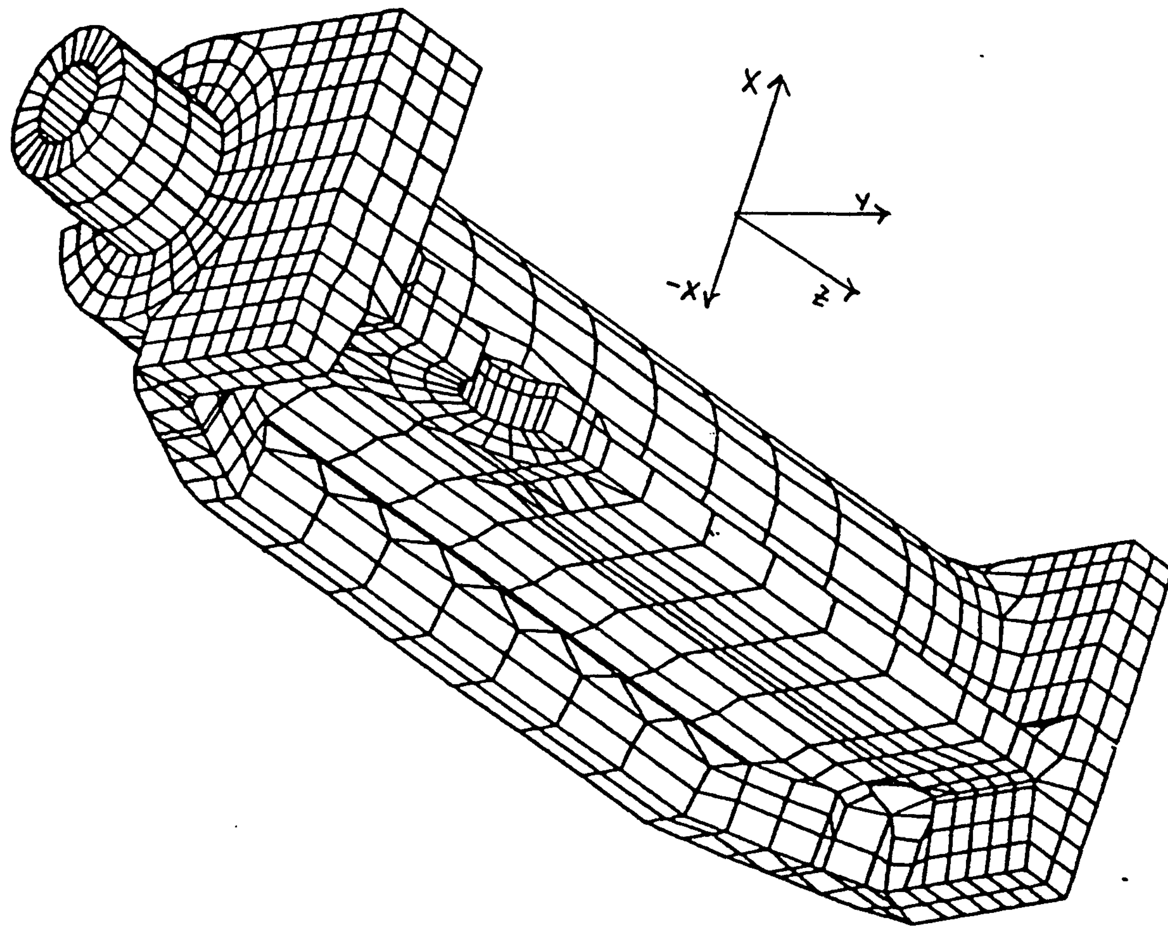


Figure 2-6 - 3-D ANSYS Model of M-1 Track Shoe, Isometric View

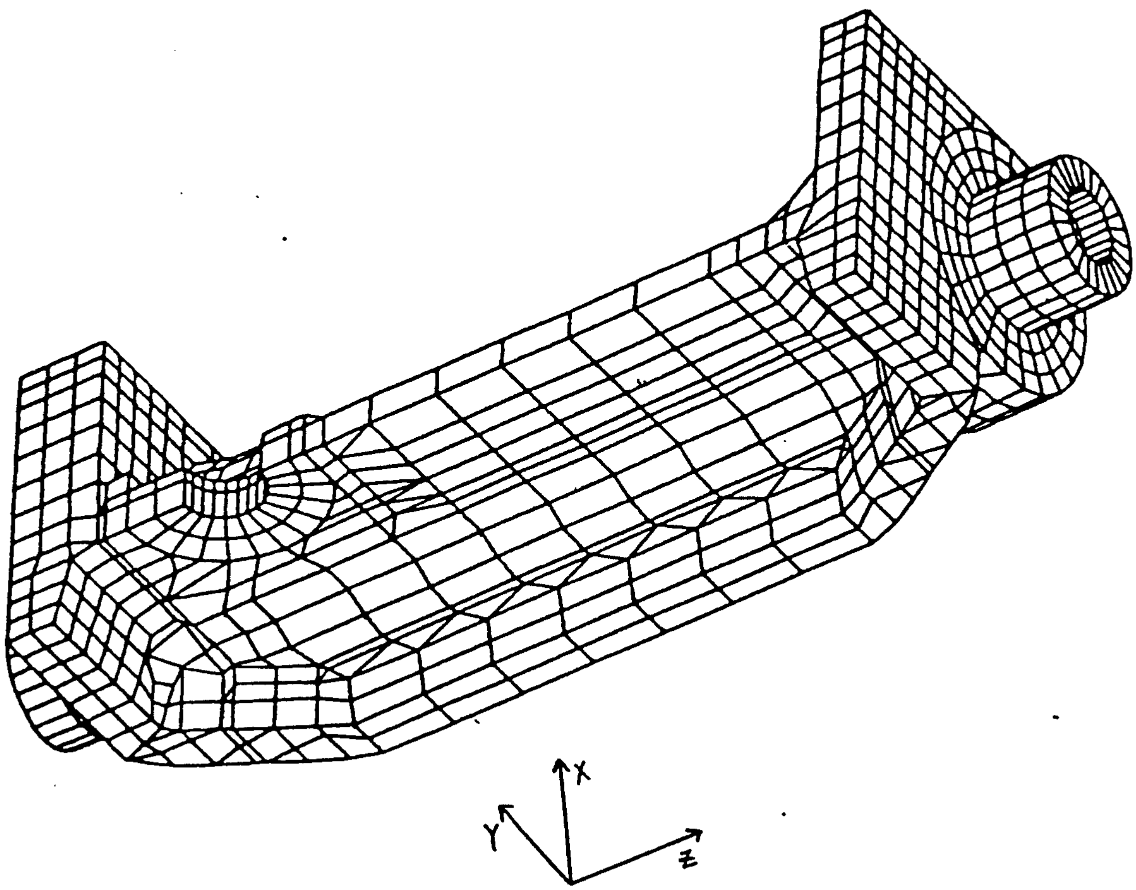
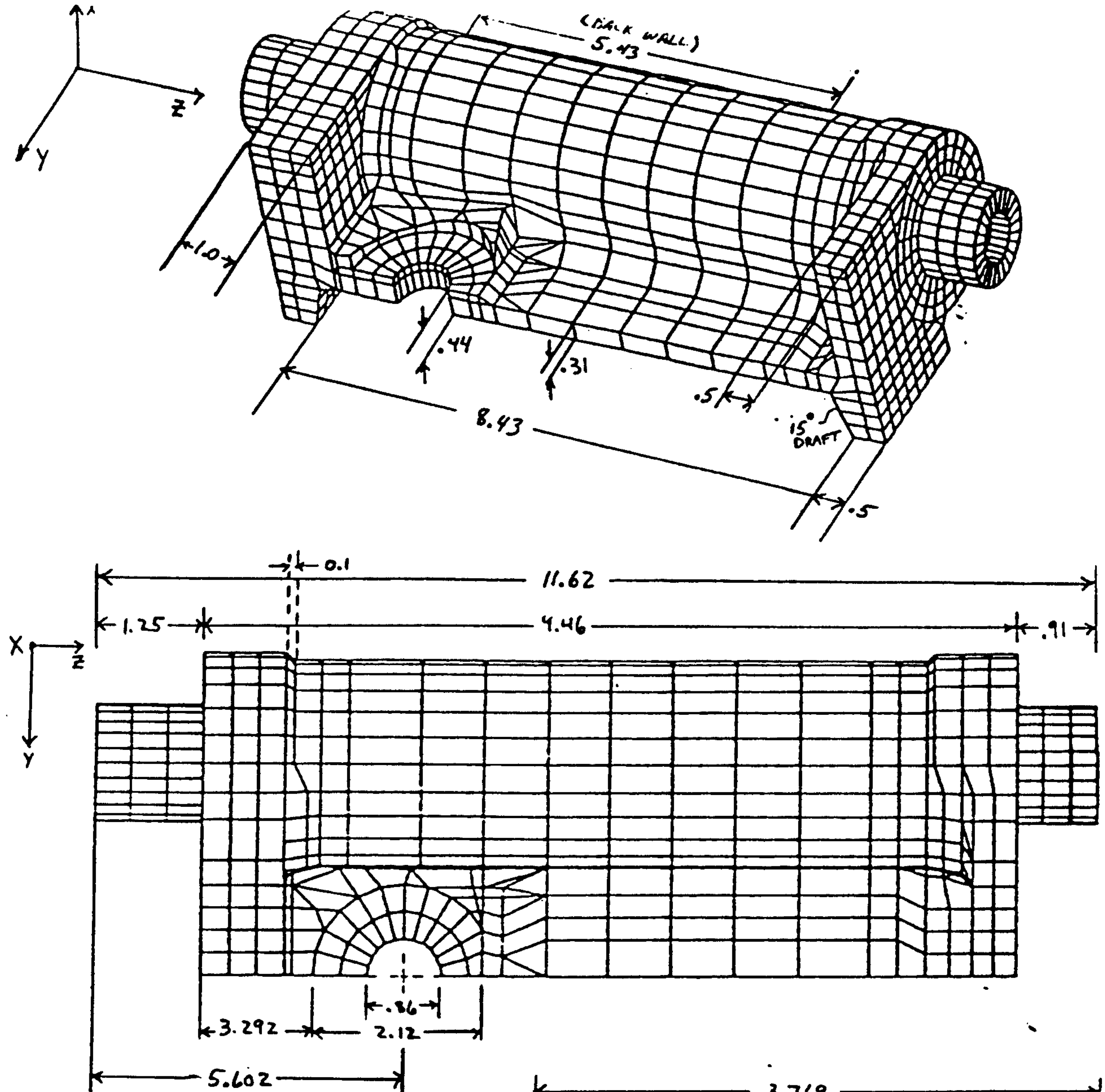


Figure 2-7 - 3-D ANSYS Model of M-1 Track Shoe, Isometric View



Model dimensions based on following reference drawings:

1. U.S. Army Tank Automotive Command, Dwg. No. XM67059

2. ALCOA Forging, Dwg. No. F-18292

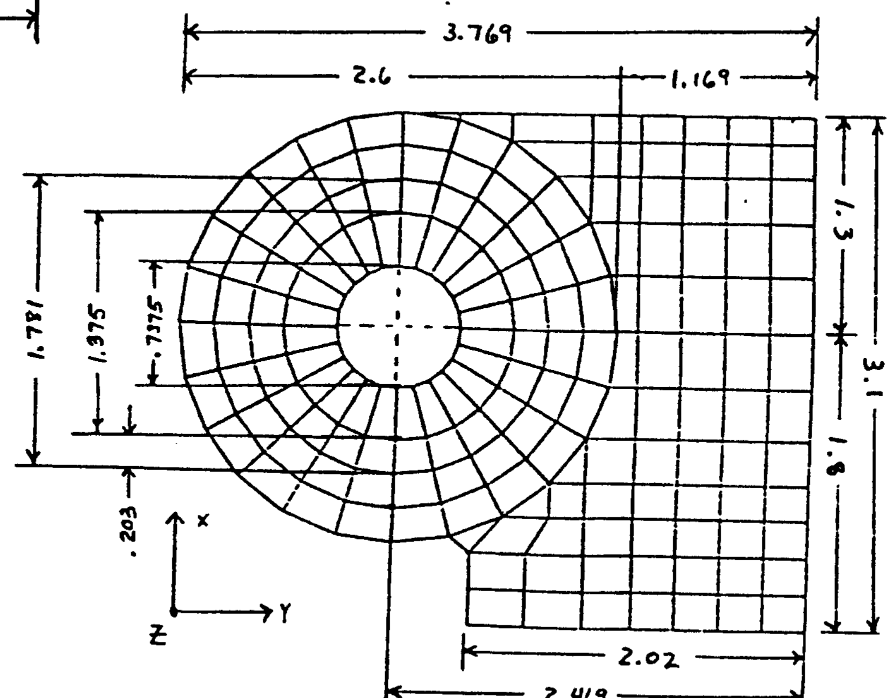
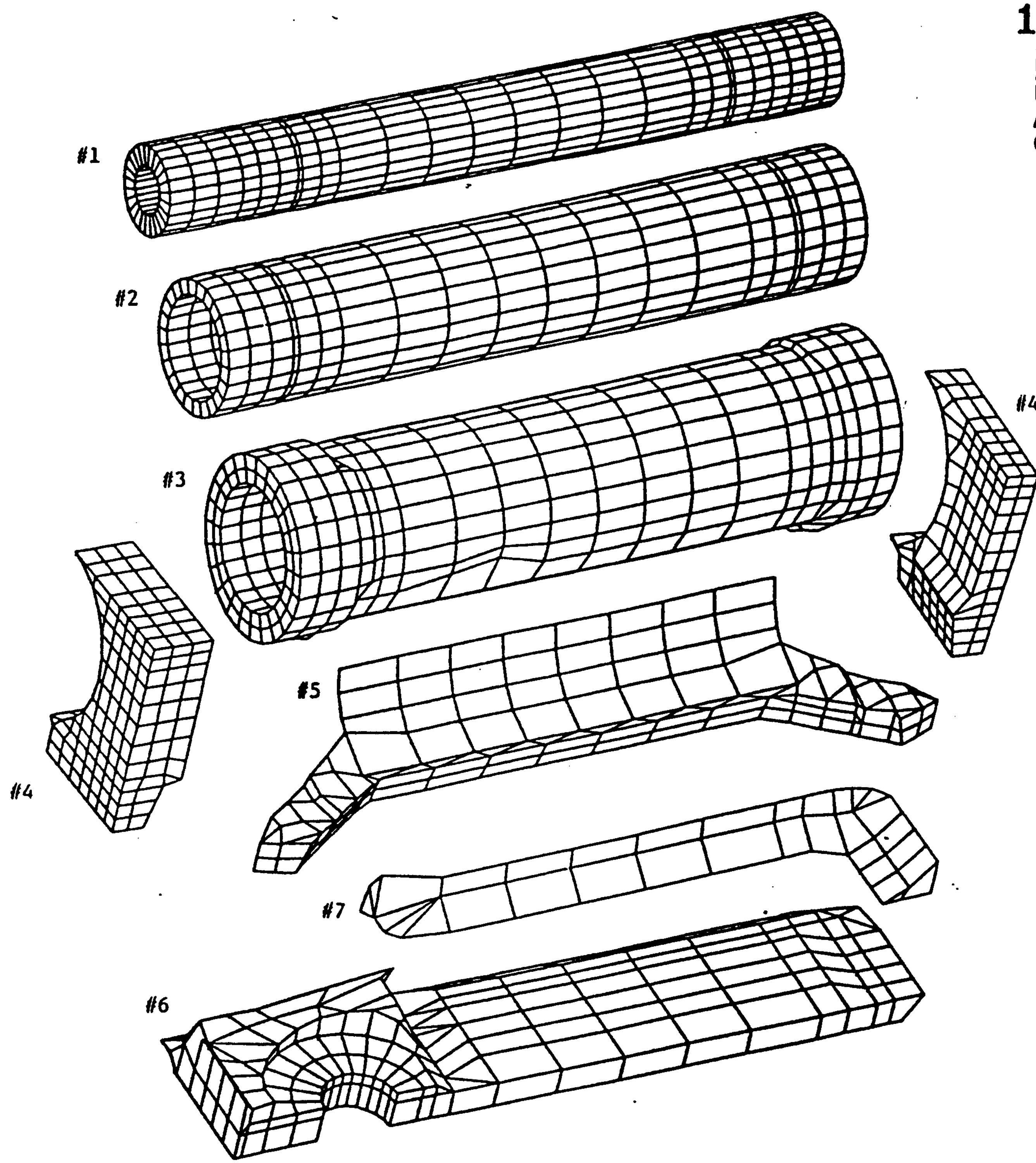
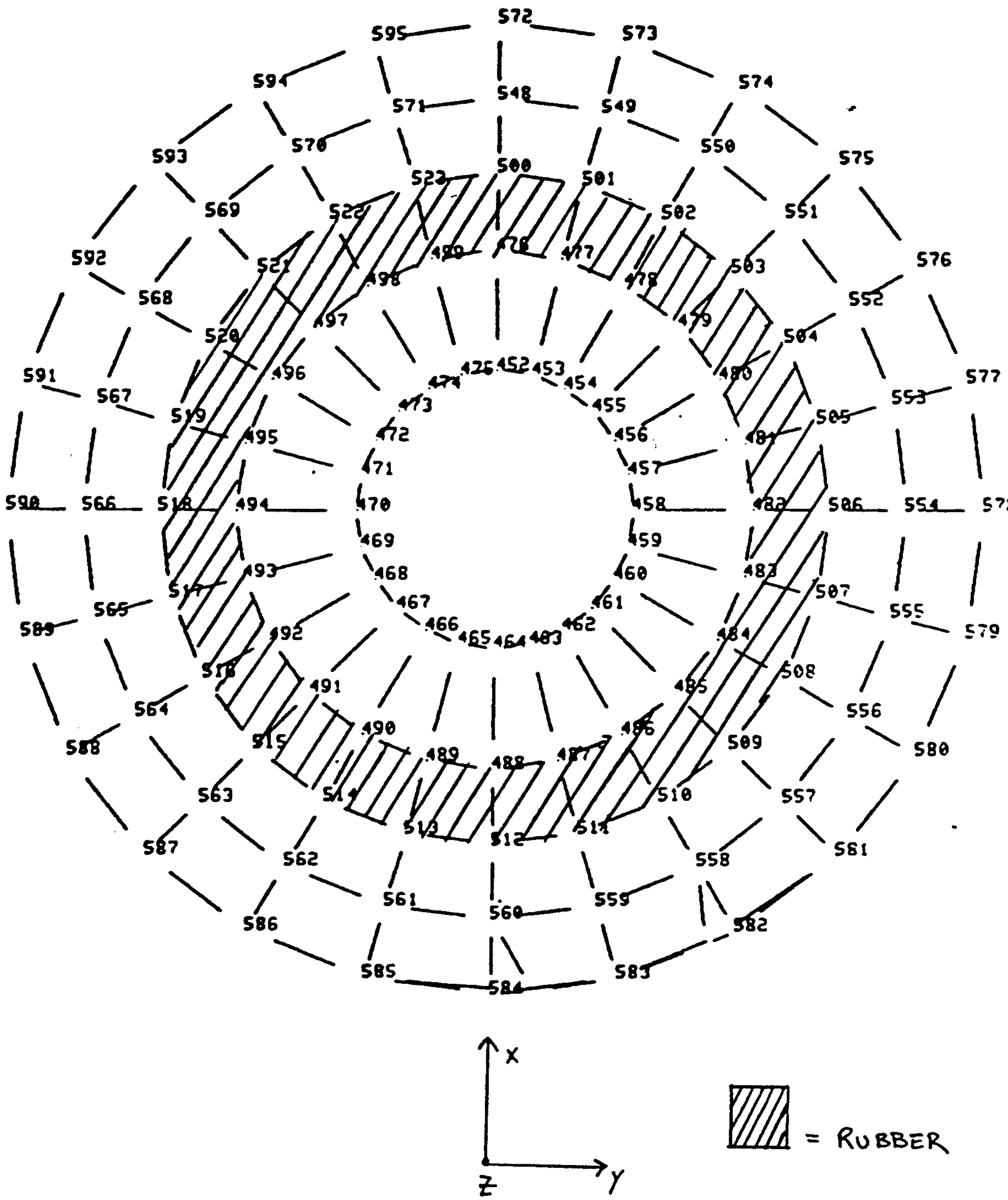


Figure 2-8 - M-1 Track Shoe Dimensions Used in Analysis



1. Steel Shaft 2. Rubber Bushing 3. Alum. Cylinder (Binocular)	Node Range { 2-3949
4. Alum. End Plate (Thick)	4001-4451
Alum. End Plate (Thin)	4618-4955
5. Alum. Rib & Intersecting Wall	5001-5543
6. Alum. Web	6001-6657
7. Alum. Fillets	7001-7019

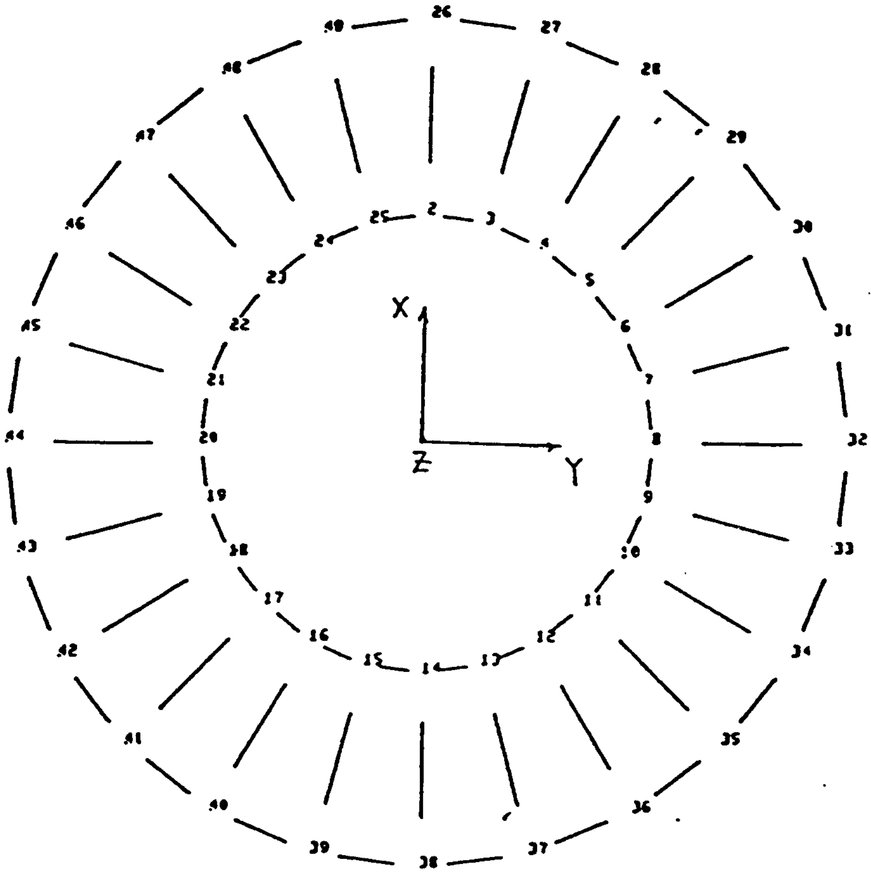
Figure 2-9 - 3-D Model Isolating the Seven Element Types



CROSS-SECTION AT Z = 1.5"

Figure 2-10 - Shaft, Bushing and Cylinder Nodes

DEAC



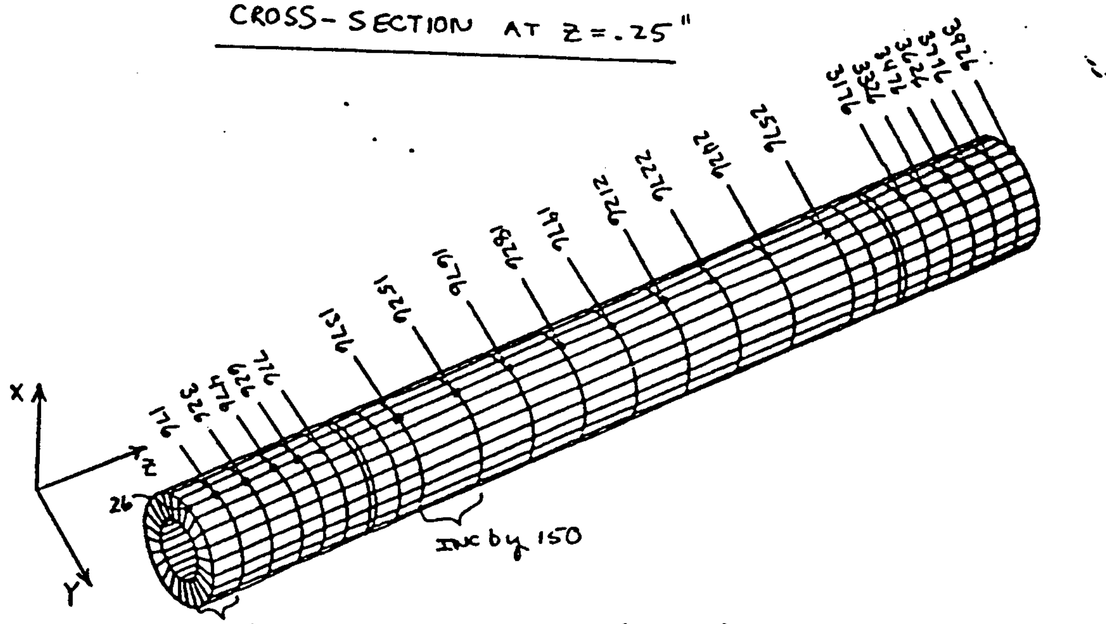
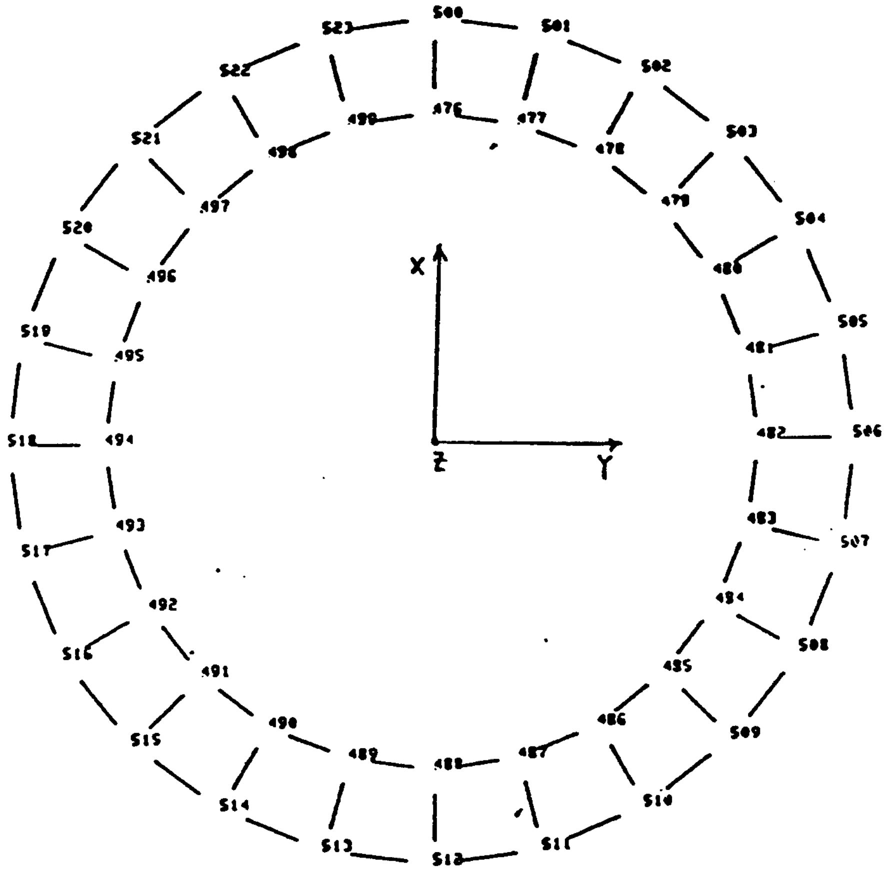
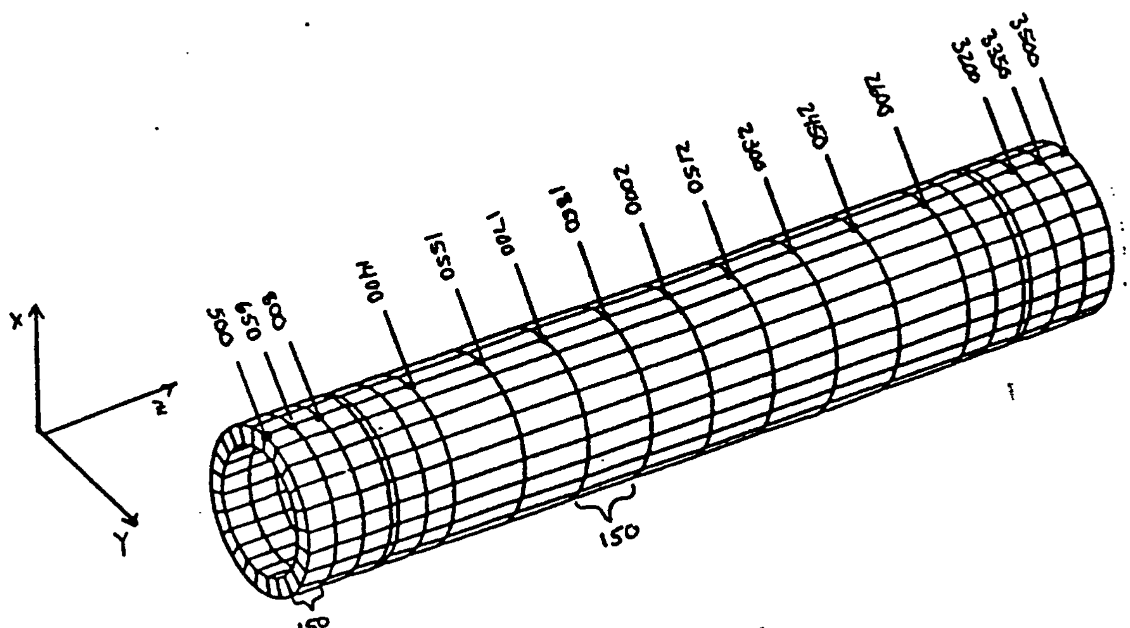


Figure 2-11 - Steel Shaft Nodes (Type 1)



CROSS-SECTION AT Z = 1.5"



ALL ROWS (RINGS) INCREMENT NODES BY 150

Figure 2-12 - Rubber Bushing Nodes (Type 2)

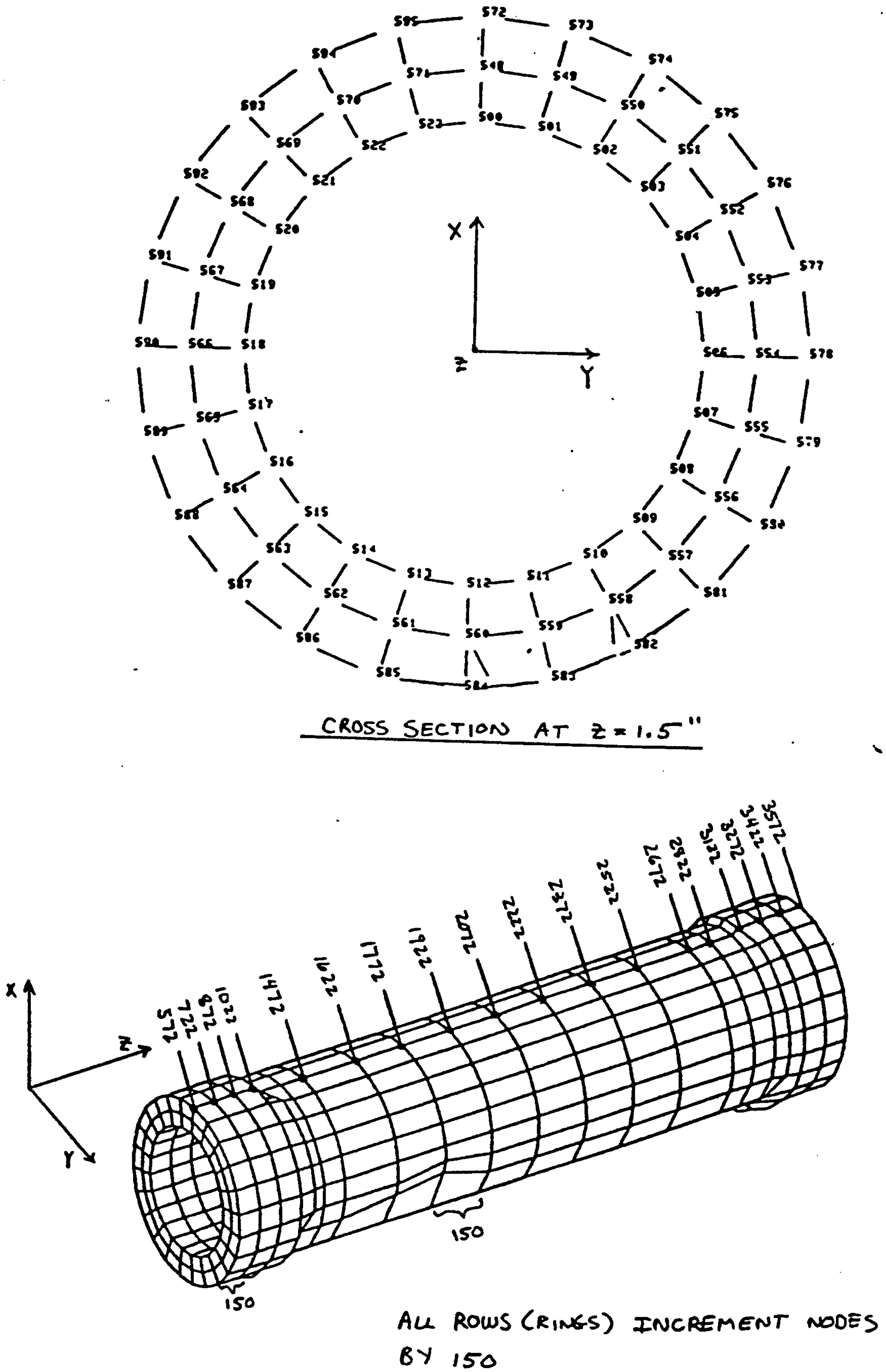


Figure 2-13 - Aluminum Cylinder (Binocular) Nodes (Type 3)

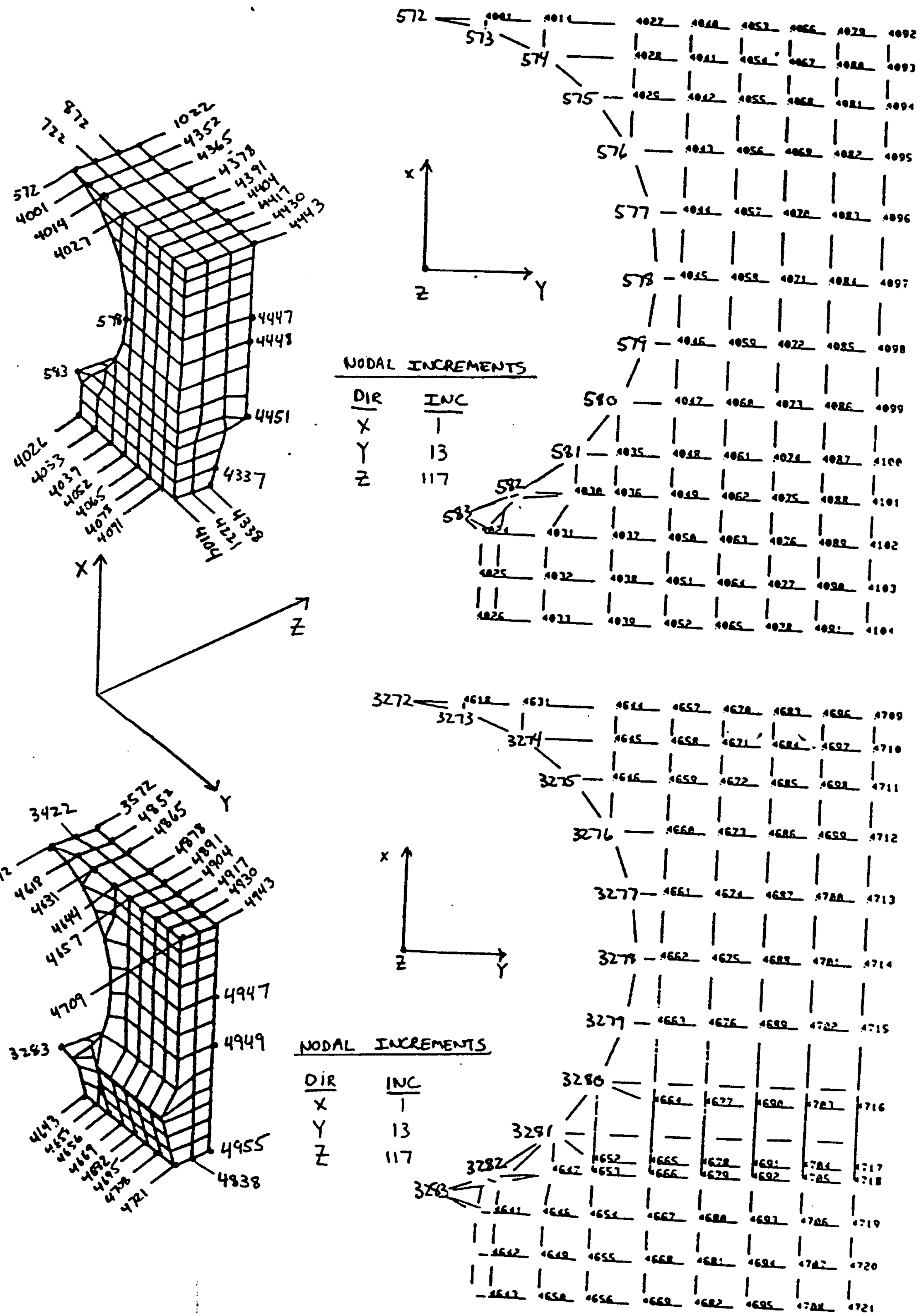


Figure 2-14 - Aluminum Endplate Nodes (Type 4)

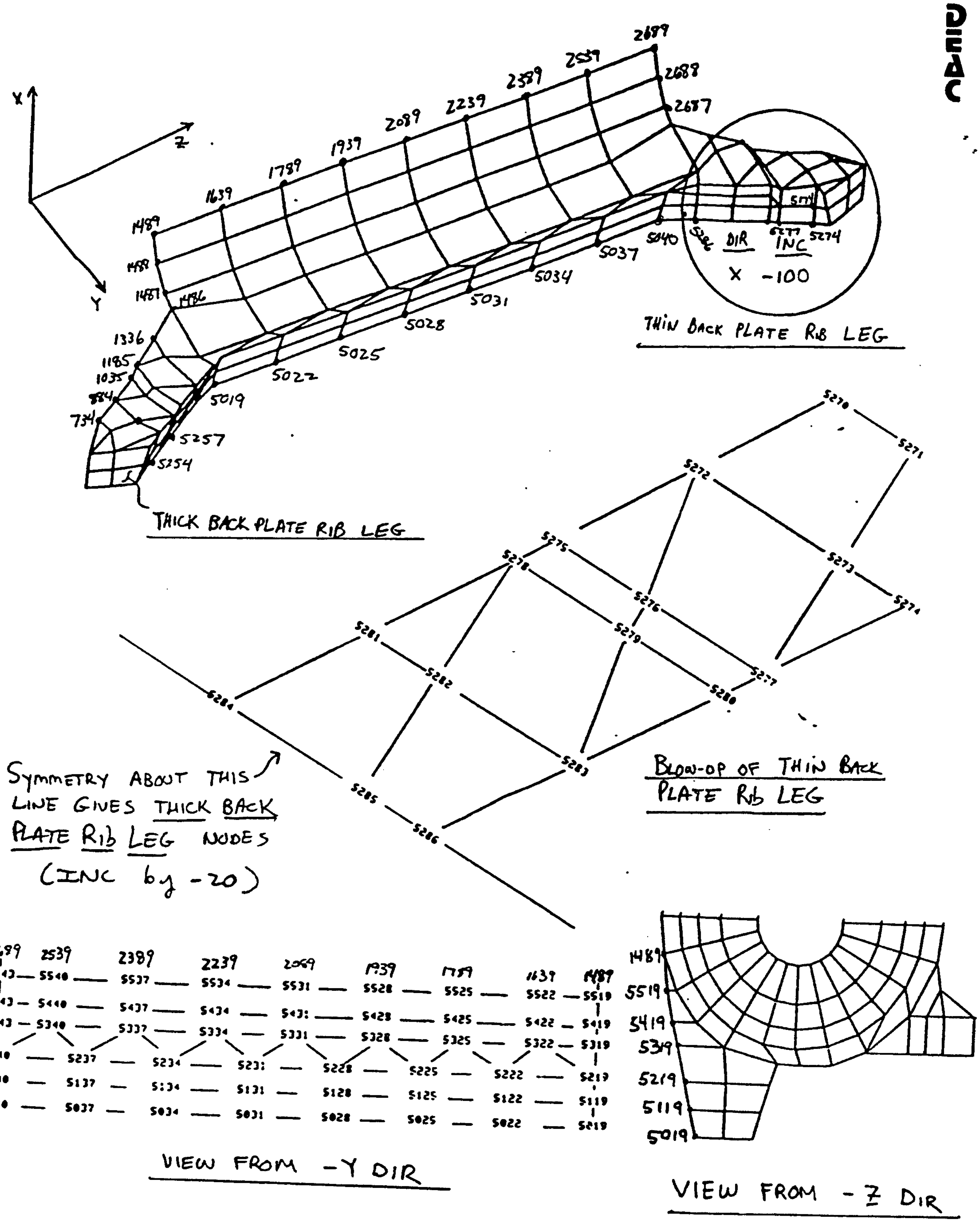


Figure 2-15 - Rib & Intersecting Wall Nodes (Type 5)

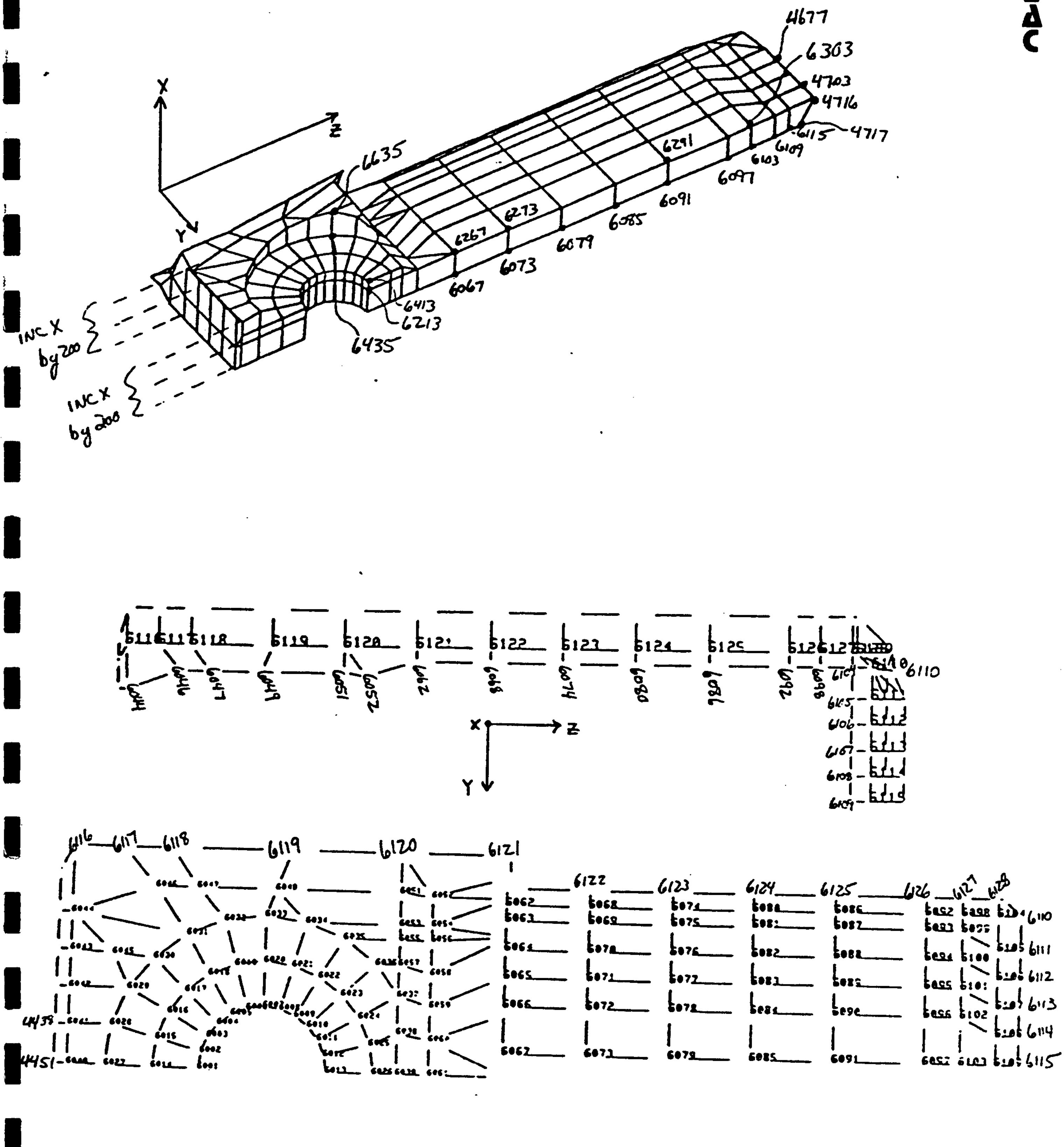


Figure 2-16 - Web Nodes (Type 6)

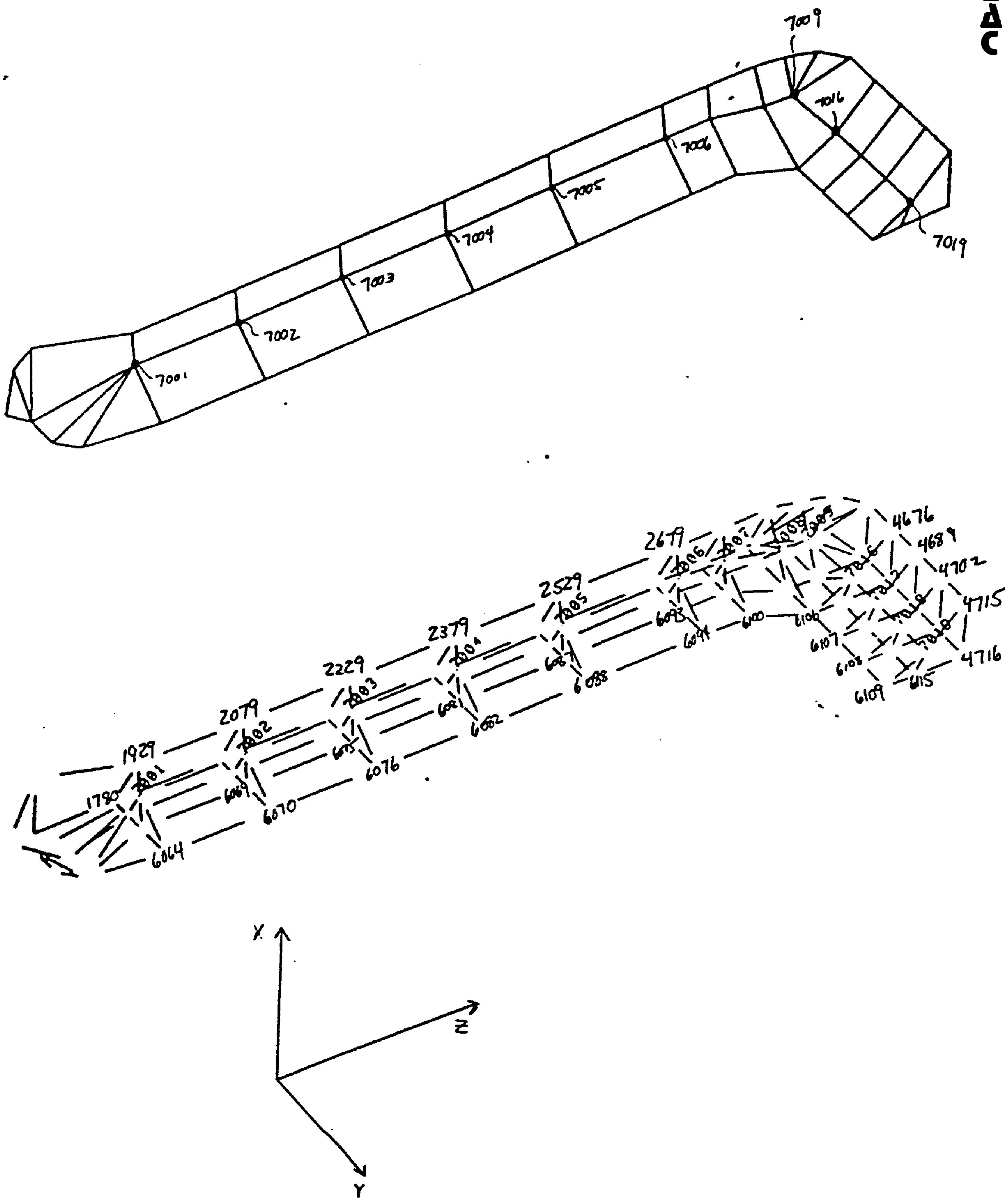


Figure 2-17 - Fillet Nodes (Type 7)

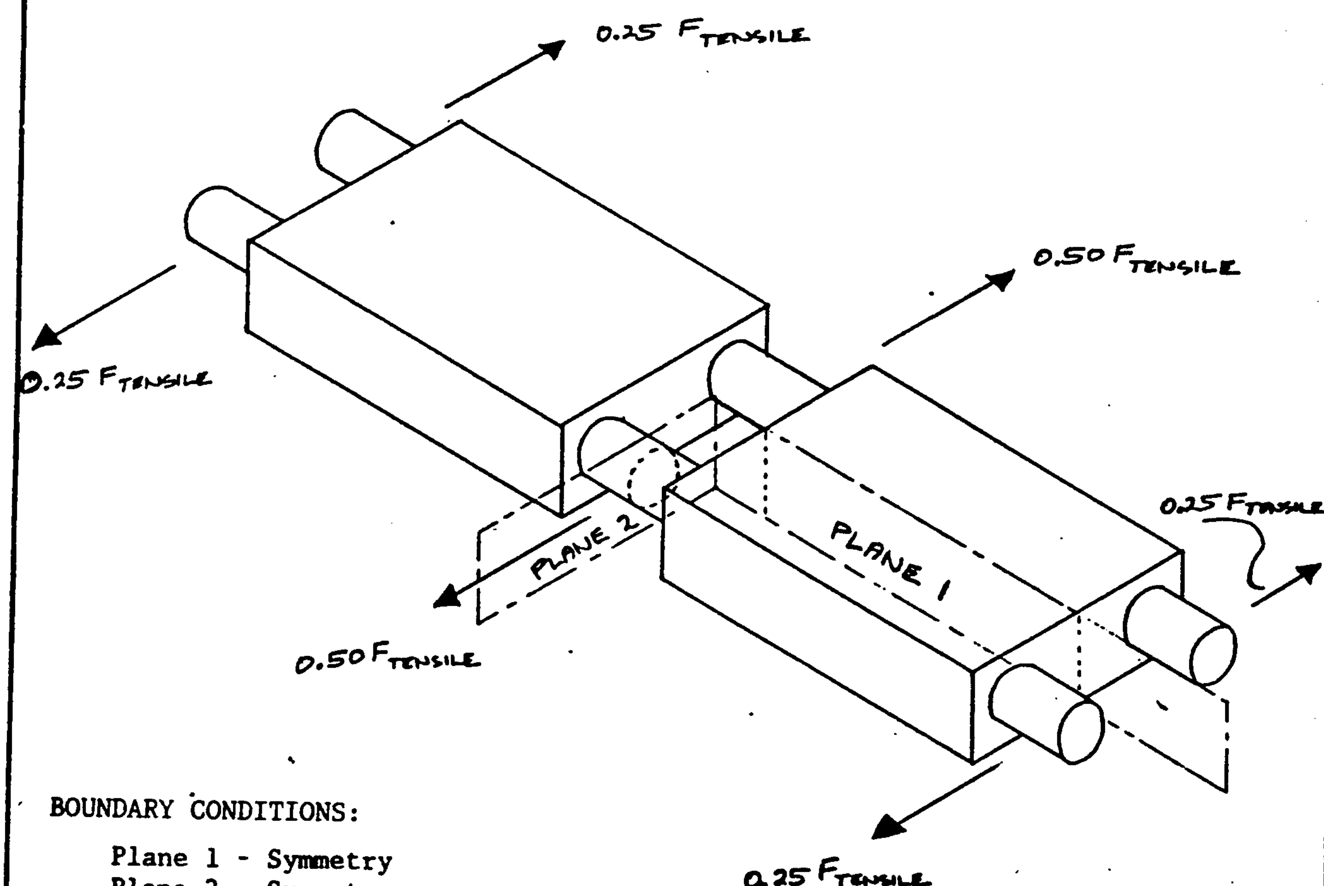
3.0 LOAD CASES

The 3-D finite element model was used to analyze three loading conditions on the shoe. The tensile and side loads will be evaluated with the quadrant model by applying the proper boundary conditions to the symmetry planes. The specific set of load cases that were analyzed are listed below:

Case 1 - Pure Tensile Load ($F_{tensile}$)
Case 2 - Out-of-Plane Load (F_{side})
Case 3 - Twisting Load (F_{twist})

These three load cases are illustrated in Figures 3-1 to 3-3.

The maximum load assumed in this analysis for Case 1 is $F_{tensile}$ = 72,000 lbs. for the shoe pair. This load corresponds to the Goodyear test (see Figure B-5) which loaded one shoe and one pin/bushing to 36,000 lbs. The maximum load assumed for Case 2 is F_{side} = 72,000 lbs. The maximum twisting load for Case 3 was assumed to be F_{twist} = 18,000 lbs. This corresponds to an applied twisting moment of $T = F_{twist} \times D$ = 18,000 lbs. x 4.94 in. = 88,920 in-lb. Since the analyses are linear, the results from any of the cases can be linearly scaled.



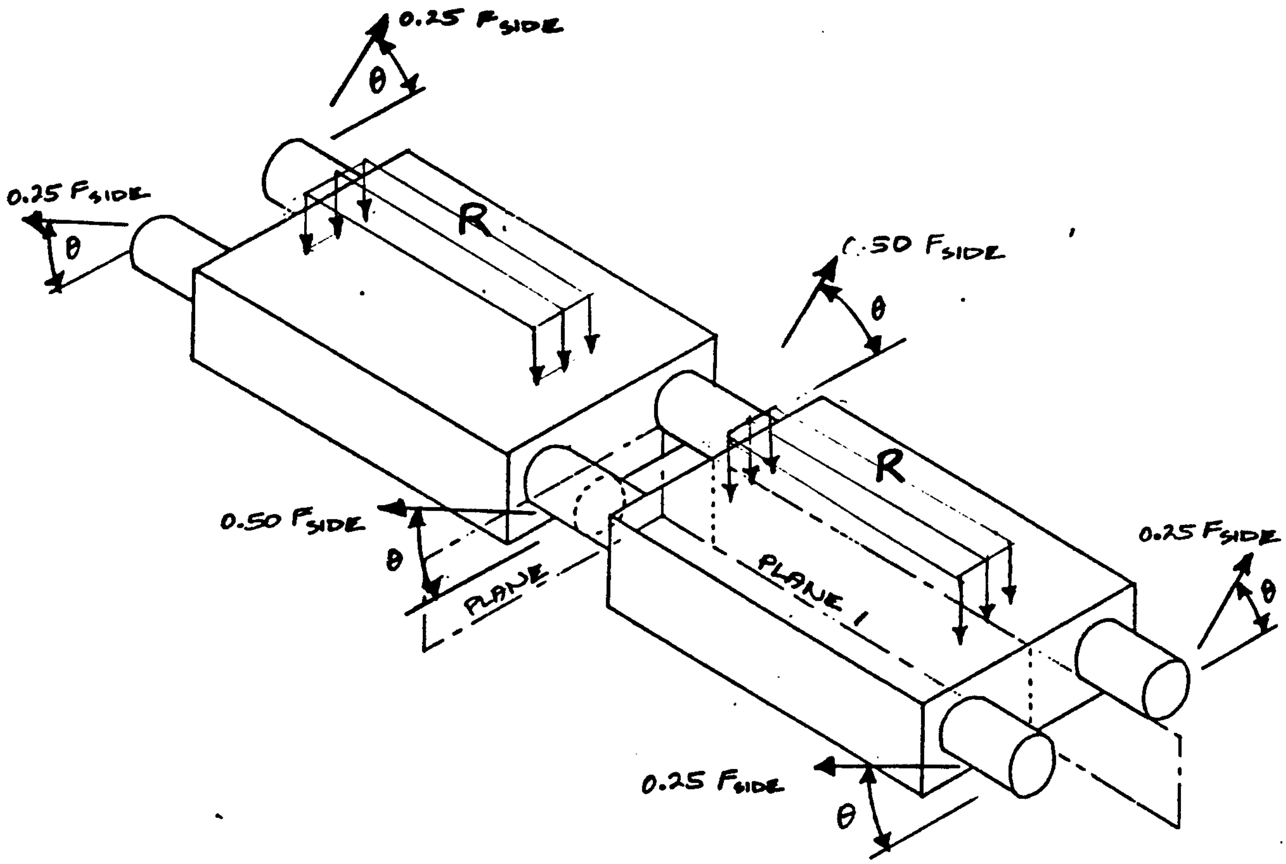
BOUNDARY CONDITIONS:

Plane 1 - Symmetry
Plane 2 - Symmetry

$F_{tensile}$ = Total Applied Tensile Load

Assume $F_{tensile}$ = 72,000 lbs. for Analysis

Figure 3-1 - Case 1 - Pure Tensile Load on Track Shoe



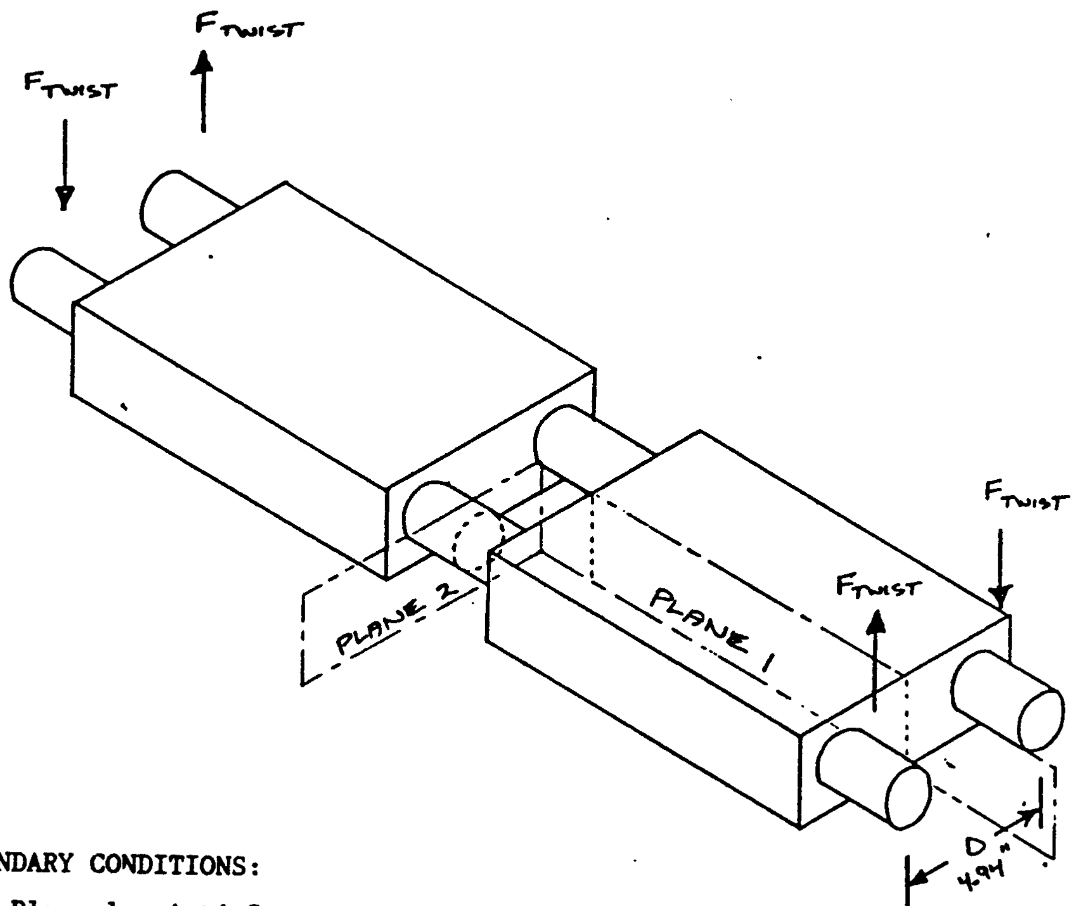
BOUNDARY CONDITIONS:

Plane 1 - Symmetry
Plane 2 - Symmetry
R = Reaction force required to balance out-of-plane component

F_{side} = Total Out-of-Plane Load at an Angle θ

Assume F_{side} = 72,000 lbs. and θ = 30° for Analysis

Figure 3-2 - Case 2 - Out-of-Plane Load on Track Shoe



BOUNDARY CONDITIONS:

Plane 1 - Anti-Symmetry
Plane 2 - Anti-Symmetry

$T = F_{twist} \times D$ = Total Applied Twisting Moment

Assume F_{twist} = 18,000 lbs. for Analysis

Figure 3-3 - Case 3 - Twisting Load on Track Shoe

4.0 MATERIAL PROPERTY DATA

The M-1 tank track shoe assembly contains three different materials: the steel shaft, the rubber bushing, and the aluminum shoe body. Two material properties are required for each material to perform a static, elastic analysis, namely: Young's modulus, E

Poisson's ratio, ν

The material properties used in the 3-D ANSYS model are listed below:

Steel Pin, ANSYS Material 1

$E = 30 \times 10^6$ psi

$\nu = .3$

Rubber Bushing, ANSYS Material 2

This material is natural rubber (NR) with an ultimate tensile strength of 3000 psi and a Shore A durometer of 65-70. Refer to Appendix B for a development of the rubber properties. The first approximation rubber properties as developed in Appendix B are:

$E = 20 \times 10^3$ psi

$\nu = .49$

These properties were modified as a result of the tensile load calibration runs performed in Section 5.2. The load-deflection test data obtained by Goodyear was used as a basis to scale the rubber modulus. The rubber properties used in the final analysis are:

$E = 4 \times 10^3$ psi

$\nu = 0$

Aluminum Shoe Body, ANSYS Material 3

$E = 10 \times 10^6$ psi

$\nu = .33$

5.0 FINITE ELEMENT STRESS ANALYSIS

This section presents the finite element stress results that were obtained with the 3-D ANSYS model described in Section 2.0. In addition to the three defined load cases in Section 3.0, a uniform temperature case was run to check out the connectivity of the model.

5.1 Uniform Temperature Check Case

As a final check of the 3-D model, a uniform temperature case was run. This is a very useful case to verify that all parts of the model are connected properly and that all displacement boundary conditions are correctly applied. The temperature of all nodes in the model was set to 1000°F and the coefficients of thermal expansion for all three materials were set to $10 \times 10^{-6}/°F$ for this case only. These conditions allow free thermal expansion of the model and the resulting stresses for each element type should be essentially zero.

A postprocessing file using POST1 was set up to sort on element type and scan for the highest stresses in each element type or component. The stress summaries are based on both element data and nodal data, and the stresses are listed in order of decreasing values of stress intensity. The stresses listed in the tables are defined below:

SIG1 = σ_1 = first principal stress value

SIG2 = σ_2 = second principal stress value

SIG3 = σ_3 = third principal stress value

SINT = SI = stress intensity = $|(\sigma_1-\sigma_3)|$ = twice the maximum shear stress

SIGE = Von Mises equivalent stress

$$= \frac{1}{\sqrt{2}} [(\sigma_1-\sigma_2)^2 + (\sigma_2-\sigma_3)^2 + (\sigma_3-\sigma_1)^2]^{\frac{1}{2}}$$

Tables 5-1 to 5-7 show the maximum stress summaries in the seven element types for the uniform temperature case. Refer to Figure 2-9 for a sketch of the various element types. The element stresses are lower than the nodal stresses because they occur at the element centroids. The tables also define the nodal points for each of the high stress elements to aid the reader in locating the elements. It is suggested that the nodal data be used as a basis for determining peak stresses since these stresses occur on the surface. Node points are described in Figures 2-10 to 2-17. The largest stress intensity was calculated to be 4.9 psi at Node 6439 which is in the shoe web (Table 5-6). Therefore, for a 1000°F temperature change, the maximum stress is essentially zero and the model is behaving as expected.

TABLE 5-1
Maximum Stress Summary
Type 1 - Steel Shaft
Uniform Temperature Case

ERSE FOR LABEL= TYPE FROM 1 TO 1 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1311	0.28916944E-01	0.36650434E-02	-0.52591500E-03	0.29442859E-01	0.27587176E-01
1370	0.28758931E-01	0.30645015E-02	-0.67290616E-03	0.29431837E-01	0.27752522E-01
1336	0.28548470E-01	0.27710773E-02	-0.18201893E-03	0.28730489E-01	0.27373671E-01
1237	0.28789939E-01	0.33906571E-02	0.79591001E-04	0.28710348E-01	0.27206348E-01
1374	-0.17376675E-03	-0.41862842E-02	-0.28752254E-01	0.28578487E-01	0.26798480E-01
1378	-0.62750787E-03	-0.37850481E-02	-0.28894566E-01	0.28267059E-01	0.26828013E-01
1306	0.27217188E-01	0.33127302E-02	-0.95083359E-03	0.28168022E-01	0.26296754E-01
1440	0.27096853E-01	0.27796245E-02	-0.92668217E-03	0.28023535E-01	0.26366483E-01
1245	-0.11085811E-02	-0.72408351E-02	-0.28503474E-01	0.27394892E-01	0.24901651E-01
1249	-0.21813339E-02	-0.64551907E-02	-0.29357676E-01	0.27176342E-01	0.25311492E-01

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1311	1	45	1	1843	1693	1669	1819	1844	1694	1670	1820
1370	1	45	1	1993	1843	1819	1969	1994	1844	1820	1970
1336	1	45	1	1994	1844	1820	1970	1995	1845	1821	1971
1237	1	45	1	1844	1694	1670	1820	1845	1695	1671	1821
1374	1	45	1	1981	1831	1807	1957	1982	1832	1808	1958
1378	1	45	1	1982	1832	1808	1958	1983	1833	1809	1959
1306	1	45	1	1842	1692	1668	1818	1843	1693	1669	1819
1440	1	45	1	1992	1842	1818	1968	1993	1843	1819	1969
1245	1	45	1	1831	1681	1657	1807	1832	1682	1658	1808
1249	1	45	1	1832	1682	1658	1808	1833	1683	1659	1809

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1833	-0.45662176E-03	-0.10795720E-01	-0.42550170E-01	0.42093548E-01	0.38000044E-01
1832	-0.28112134E-03	-0.88932180E-02	-0.42293113E-01	0.42011991E-01	0.38440697E-01
1844	0.39484827E-01	0.14099918E-02	-0.16402485E-02	0.41125075E-01	0.39688119E-01
1843	0.39446861E-01	0.29708572E-02	-0.99387612E-03	0.40440737E-01	0.38611632E-01
1845	0.37232163E-01	0.59521064E-03	-0.26025878E-02	0.39834751E-01	0.38336397E-01
1831	0.44061060E-04	-0.60047576E-02	-0.38777964E-01	0.38822026E-01	0.36180696E-01
1834	-0.54387869E-03	-0.11071322E-01	-0.39245415E-01	0.38701536E-01	0.34662048E-01
1842	0.36808333E-01	0.47224417E-02	-0.71147209E-03	0.37519805E-01	0.35119746E-01
1683	-0.16288469E-02	-0.10885658E-01	-0.38638532E-01	0.37009685E-01	0.33389871E-01
1682	-0.12049235E-02	-0.99279697E-02	-0.38070526E-01	0.36865602E-01	0.33377942E-01

TABLE 5-2
Maximum Stress Summary
Type 2 - Rubber Bushing
Uniform Temperature Case

ERSE FOR LABEL= TYPE FROM 2 TO 2 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
858	0.11453294E-01	0.10884365E-01	0.10845065E-01	0.60822912E-03	0.58956247E-03
861	0.92310237E-02	0.86723375E-02	0.86496073E-02	0.58141641E-03	0.57039109E-03
855	0.11228152E-01	0.10709357E-01	0.10662347E-01	0.56580493E-03	0.54382585E-03
718	0.10448086E-01	0.99294560E-02	0.98957802E-02	0.55230623E-03	0.53626194E-03
720	0.83412131E-02	0.78380217E-02	0.77893617E-02	0.55185143E-03	0.52920193E-03
614	0.71303906E-02	0.66821779E-02	0.66120891E-02	0.51830145E-03	0.48705412E-03
613	0.88234860E-02	0.83618761E-02	0.83054520E-02	0.51803396E-03	0.49225326E-03
864	0.55613063E-02	0.51318536E-02	0.50541532E-02	0.50715308E-03	0.47311267E-03
716	0.10206244E-01	0.97377534E-02	0.97002765E-02	0.50596725E-03	0.48830862E-03
722	0.48761888E-02	0.44836304E-02	0.43811765E-02	0.49501224E-03	0.45256821E-03

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
858	2	45	2	1408	1258	1234	1384	1409	1259	1235	1385
861	2	45	2	1409	1259	1235	1385	1410	1260	1236	1386
855	2	45	2	1407	1257	1233	1383	1408	1258	1234	1384
718	2	45	2	1258	1108	1084	1234	1259	1109	1085	1235
720	2	45	2	1259	1109	1085	1235	1260	1110	1086	1236
614	2	45	2	1109	959	935	1085	1110	960	936	1086
613	2	45	2	1108	958	934	1084	1109	959	935	1085
864	2	45	2	1410	1260	1236	1386	1411	1261	1237	1387
716	2	45	2	1257	1107	1083	1233	1258	1108	1084	1234
722	2	45	2	1260	1110	1086	1236	1261	1111	1087	1237

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1258	0.71078040E-02	0.57017507E-02	0.49330573E-02	0.21747467E-02	0.19104934E-02
1259	0.64581186E-02	0.51588875E-02	0.44857661E-02	0.19723525E-02	0.17370327E-02
1257	0.64239353E-02	0.51610127E-02	0.44549642E-02	0.19689711E-02	0.17280625E-02
1108	0.61766440E-02	0.50116832E-02	0.42688574E-02	0.19077865E-02	0.16664268E-02
1408	0.56027545E-02	0.43383775E-02	0.38483389E-02	0.17544156E-02	0.15810340E-02
1109	0.56282328E-02	0.45538670E-02	0.38927175E-02	0.17355154E-02	0.15177227E-02
1234	0.87098131E-02	0.76481785E-02	0.69828827E-02	0.17269304E-02	0.15094416E-02
1107	0.55058672E-02	0.44795050E-02	0.38081374E-02	0.16977298E-02	0.14817981E-02
1409	0.51710537E-02	0.40069823E-02	0.35444436E-02	0.16266101E-02	0.14592949E-02
1235	0.79000305E-02	0.69325254E-02	0.63287058E-02	0.15713248E-02	0.13741526E-02

TABLE 5-3
Maximum Stress Summary
Type 3 - Shoe Binocular
Uniform Temperature Case

ERSE FOR LABEL= TYPE FROM 3 TO 3 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1002	0.14090108	0.53014243E-02	-0.10608994	0.24699102	0.21424270
662	0.15608250	0.20027122E-01	-0.88755074E-01	0.24483757	0.21247361
909	0.17027278	0.83685448E-02	-0.71994928E-01	0.24226771	0.21373454
998	0.12499964	-0.96611244E-02	-0.11528737	0.24028702	0.20860043
910	0.17061667	0.47323730E-03	-0.56306348E-01	0.22692302	0.20453211
908	0.12944239	-0.25415531E-01	-0.97125492E-01	0.22656788	0.20056957
1004	0.10892708	-0.94465625E-03	-0.11179432	0.22072140	0.19115096
1006	0.13521272	-0.14403837E-02	-0.84352336E-01	0.21956506	0.19203812
1140	0.82041496E-01	-0.22621951E-02	-0.13715743	0.21919892	0.19150980
1133	0.89985650E-01	0.10549017E-01	-0.12729543	0.21728108	0.19042366

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1002	3	45	3	1631	1481	1457	1607	1632	1482	1458	1608
662	3	45	3	1181	1031	1007	1157	1182	1032	1008	1158
909	3	45	3	1481	1331	1307	1457	1482	1332	1308	1458
998	3	45	3	1630	1480	1456	1606	1631	1481	1457	1607
910	3	45	3	1482	1332	1308	1458	1483	1333	1309	1459
908	3	45	3	1480	1330	1306	1456	1481	1331	1307	1457
1004	3	45	3	1608	1458	1410	1560	1609	1459	1411	1561
1006	3	45	3	1632	1482	1458	1608	1633	1483	1459	1609
1140	3	45	3	1781	1631	1607	1757	1782	1632	1608	1758
1133	3	45	3	1780	1630	1606	1756	1781	1631	1607	1757

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1482	0.31707037	0.28633241E-01	-0.37903123E-01	0.35497350	0.32804943
1481	0.27503294	0.22501589E-01	-0.60675474E-01	0.33570841	0.30571807
1332	0.28345154	0.16128552E-01	-0.19020729E-01	0.30247227	0.28766501
1782	0.27168386E-01	-0.24608422E-01	-0.26194550	0.28911389	0.26785892
1781	0.44747648E-01	-0.15867725E-01	-0.23398346	0.27873111	0.25536236
1632	0.13330580	0.34614453E-02	-0.13610035	0.26940615	0.23495813
1331	0.22720368	0.56506562E-03	-0.37972986E-01	0.26517667	0.25086772
1410	0.11146849	-0.12023570E-02	-0.13247637	0.24394486	0.21208629
1631	0.11585947	0.20731090E-03	-0.12796087	0.24382033	0.21405384
1182	0.23800097	0.44074373E-01	-0.42782560E-02	0.24227923	0.22381608

TABLE 5-4
Maximum Stress Summary
Type 4 - Shoe End Plates
Uniform Temperature Case

ERSE FOR LABEL= TYPE FROM 4 TO 4 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
399	0.24120722	0.21699120E-01	-0.38413528	0.62534250	0.54951734
471	-0.88981633E-01	-0.26216159	-0.70678405	0.61780242	0.55197838
432	0.35847221	0.72169196E-01	-0.25295301	0.61142522	0.52986539
429	0.43563460	0.76170141E-01	-0.16979678	0.60543138	0.52738107
360	0.36630071	0.55606187E-01	-0.17677191	0.54307262	0.47194202
468	-0.86689199E-01	-0.25701321	-0.58160937	0.49492017	0.43549909
396	0.17829438	-0.33177944E-02	-0.30643154	0.48472592	0.42415808
426	0.32358430	0.36541027E-01	-0.12673396	0.45031826	0.39486649
474	0.88824069E-03	-0.15001622	-0.42897191	0.42986015	0.37773548
333	0.24951477	0.28257734E-01	-0.14517441	0.39468918	0.34264627

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
399	4	45	3	4307	4320	4321	4308	4424	4437	4438	4425
471	4	45	3	4320	4333	4334	4321	4437	4450	4451	4438
432	4	45	3	4308	4425	4309	4309	4321	4438	4322	4322
429	4	45	3	4295	4412	4296	4296	4308	4425	4309	4309
360	4	45	3	4294	4307	4308	4295	4411	4424	4425	4412
468	4	45	3	4319	4332	4333	4320	4436	4449	4450	4437
396	4	45	3	4306	4319	4320	4307	4423	4436	4437	4424
426	4	45	3	4282	4399	4283	4283	4295	4412	4296	4296
474	4	45	3	4321	4438	4322	4322	4334	4451	4335	4335
333	4	45	3	4293	4306	4307	4294	4410	4423	4424	4411

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
4438	0.23623476	-0.67020159E-01	-0.72969209	0.96592685	0.85586951
4437	0.17078370	-0.60801266E-01	-0.77977943	0.95056313	0.86082032
4450	-0.24068515	-0.74874053	-1.1665937	0.92590859	0.80312874
4451	-0.33835192	-0.64844641	-1.2556118	0.91725991	0.82929062
4425	0.39614796	0.31462328E-01	-0.32693285	0.72308081	0.63356941
4424	0.32440791	-0.13770356E-01	-0.31422120	0.63862911	0.56030745
4436	0.15210141	-0.72769059E-01	-0.44023786	0.59233927	0.51847159
4333	-0.49797070E-01	-0.16047249	-0.62784358	0.57804651	0.54035496
4308	0.26570104	0.36748157E-01	-0.22497648	0.49067752	0.42771982
4412	0.39071474	0.65423495E-01	-0.98601761E-01	0.48931650	0.43275307

TABLE 5-5
Maximum Stress Summary
Type 5 - Shoe Rib and Wall
Uniform Temperature Case

ERSE FOR LABEL- TYPE FROM 5 TO 5 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1047	0.65526171E-01	0.63245755E-02	-0.38035505E-01	0.10356168	0.89993517E-01
1048	0.88130272E-01	0.33205774E-01	-0.25273573E-02	0.90657629E-01	0.79096026E-01
496	-0.68026647E-03	-0.15061982E-01	-0.67990623E-01	0.67310356E-01	0.61396086E-01
1051	0.39770762E-01	-0.34315765E-02	-0.22148228E-01	0.61918990E-01	0.55003256E-01
1157	0.24138704E-01	-0.34529836E-02	-0.36255415E-01	0.60394119E-01	0.52367692E-01
1049	0.29252833E-01	-0.18283331E-02	-0.30929031E-01	0.60181864E-01	0.52128429E-01
925	0.28529565E-01	0.44419567E-02	-0.29268557E-01	0.57798121E-01	0.50285358E-01
680	-0.67898805E-02	-0.15978524E-01	-0.56136058E-01	0.49346178E-01	0.45453845E-01
1158	0.29262564E-01	0.30351381E-03	-0.19926499E-01	0.49189063E-01	0.42821980E-01
1287	0.26456446E-02	-0.83981815E-02	-0.46237624E-01	0.48883269E-01	0.44403623E-01

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1047	5	45	3	1484	5066	5218	5218	5065	5065	5065	5065
1048	5	45	3	1485	1484	5218	5218	5065	5065	5065	5065
496	5	45	3	5154	4259	4142	4142	882	4258	4141	4141
1051	5	45	3	5218	5220	5065	5065	1485	1485	1485	1485
1157	5	45	3	5220	5223	1636	1636	5218	5224	1635	1635
1049	5	45	3	1486	5220	1636	1636	1485	5218	1635	1635
925	5	45	3	5062	5065	5066	5063	1335	1485	1484	1334
680	5	45	3	5155	5058	5059	5156	1035	1185	1184	1034
1158	5	45	3	1636	1786	5223	5223	1635	1785	5224	5224
1287	5	45	3	5223	5226	1786	1786	5224	5227	1785	1785

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1635	0.43688178E-01	-0.25844949E-02	-0.51937956E-01	0.95626134E-01	0.82937840E-01
1484	0.66623636E-01	0.12503917E-01	-0.28171963E-01	0.94795600E-01	0.82413455E-01
4141	-0.39947769E-01	-0.49085791E-01	-0.12871418	0.88766408E-01	0.84999704E-01
1485	0.51094495E-01	0.90228934E-02	-0.28293137E-01	0.79387632E-01	0.69241561E-01
4258	0.29540603E-01	0.13976922E-02	-0.46564486E-01	0.76105089E-01	0.66649751E-01
5218	0.43566323E-01	0.58186070E-02	-0.27081842E-01	0.70648165E-01	0.61641588E-01
1785	0.13692277E-01	-0.15127939E-01	-0.55624327E-01	0.69316604E-01	0.62428637E-01
5066	0.37116952E-01	-0.11434357E-02	-0.28742555E-01	0.65859507E-01	0.57324275E-01
4259	0.57239835E-01	0.24600707E-01	-0.57142998E-02	0.62954135E-01	0.58973838E-01
1489	0.69067155E-01	0.38904197E-01	0.74198732E-02	0.61647282E-01	0.53392200E-01

TABLE 5-6
Maximum Stress Summary
Type 6 - Shoe Web
Uniform Temperature Case

ERSE FOR LABEL= TYPE FROM 6 TO 6 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1524	0.92951838	-0.16287642	-2.7124288	3.6419472	3.2370761
1526	1.4426451	0.57186630	-2.1524660	3.5951111	3.2484662
1527	-0.22175608	-0.79873226	-3.0298457	2.8080896	2.5686705
1528	-0.10191296	-0.57557894	-2.6877668	2.5858539	2.3845689
824	1.8998953	0.28065880E-01	-0.58515727	2.4850526	2.2422393
946	2.8020108	1.2404116	0.41658463	2.3854262	2.0985163
822	1.7988599	0.39310870E-03	-0.41633123	2.2151911	2.0390211
823	1.6483439	0.83280709E-01	-0.54517582	2.1935197	1.9565159
945	2.3467245	0.82581980	0.27420974	2.0725147	1.8591318
692	1.3202031	0.31550619	-0.37364496	1.6938480	1.4753756

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1524	6	45	3	6039	6061	6060	6038	6239	6261	6260	6238
1526	6	45	3	6239	6439	6261	6261	6238	6438	6260	6260
1527	6	45	3	6025	6038	6039	6026	6225	6238	6239	6226
1528	6	45	3	6225	6238	6239	6226	6425	6438	6439	6426
824	6	45	3	6040	6027	6028	6041	6240	6227	6228	6241
946	6	45	3	6214	6227	6228	6215	6414	6427	6428	6415
822	6	45	3	6240	6227	6228	6241	6440	6427	6428	6441
823	6	45	3	6440	6427	6428	6441	6640	6627	6628	6641
945	6	45	3	6014	6027	6028	6015	6214	6227	6228	6215
692	6	45	3	4437	6441	6641	4436	4424	6442	6642	4423

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
6439	0.13455937	-0.87417689	-4.7693749	4.9039343	4.4857669
6627	3.7287740	0.45451990	-1.1193829	4.8481570	4.2838380
6239	-0.15711539	-1.2944397	-4.9748862	4.8177709	4.4098857
6039	0.36862745E-01	-0.87402840	-4.5650234	4.6018862	4.2521682
6427	3.9158523	1.0314594	0.39140502E-01	3.8767118	3.5135991
6261	3.1498462	1.0033608	-0.58778435	3.7376306	3.2888647
6227	3.7933361	1.1802811	0.37051032	3.4228258	3.1322494
6027	3.4065467	0.85873024	0.25183649	3.1547102	2.9156820
6038	0.33722432	0.10221865E-01	-2.7051763	3.0424006	2.8951690
6438	0.12720657	-0.51945169	-2.8754248	3.0026314	2.7459679

TABLE 5-7
Maximum Stress Summary
Type 7 - Shoe Fillets
Uniform Temperature Case

ERSE FOR LABEL= TYPE FROM 7 TO 7 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1265	0.40867199E-01	-0.41767191E-01	-0.36855363	0.40942083	0.37499549
1395	0.10985345	-0.13540919E-01	-0.17019154	0.28004499	0.24309544
1255	-0.47752747E-01	-0.99192022E-01	-0.21196969	0.16421695	0.14548541
1254	-0.40346258E-02	-0.37066651E-01	-0.15951307	0.15547844	0.14187633
1393	0.52224799E-01	-0.66844933E-02	-0.59135269E-01	0.11136007	0.96494698E-01
1394	0.61663468E-01	0.48544998E-02	-0.37118492E-01	0.98781960E-01	0.85868698E-01
1380	0.45560402E-01	0.14024556E-01	-0.27401069E-02	0.48300509E-01	0.42476480E-01
1516	0.41908635E-01	0.33273675E-02	-0.47606571E-02	0.46669292E-01	0.43196951E-01
1477	0.26714384E-01	-0.40412732E-02	-0.18562919E-01	0.45277302E-01	0.40042619E-01
1473	0.27210786E-02	-0.69906578E-02	-0.22925638E-01	0.25646717E-01	0.22427611E-01

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1265	7	45	3	6451	6453	6254	6254	7001	7001	7001	7001
1395	7	45	3	6263	6264	7001	7001	6254	6254	6254	6254
1255	7	45	3	1780	6451	1779	1779	6651	6651	6651	6651
1254	7	45	3	1780	1930	1929	1779	6252	6262	7001	6451
1393	7	45	3	7001	6262	6263	6263	7002	6268	6269	6269
1394	7	45	3	6264	6263	7001	7001	6270	6269	7002	7002
1380	7	45	3	6262	1930	1929	7001	6268	2080	2079	7002
1516	7	45	3	6270	6269	7002	7002	6276	6275	7003	7003
1477	7	45	3	7002	6268	6269	6269	7003	6274	6275	6275
1473	7	45	3	6268	2080	2079	7002	6274	2230	2229	7003

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
6453	0.40867198E-01	-0.41767184E-01	-0.36855363	0.40942082	0.37499549
6254	0.75360321E-01	-0.27654062E-01	-0.26937259	0.34473291	0.30904547
6451	0.93250783E-02	-0.54616658E-01	-0.24603639	0.25536147	0.23050908
6264	0.69014606E-01	-0.24173280E-01	-0.15489411	0.22390872	0.19494341
6252	0.45497962E-01	-0.39056792E-01	-0.16946167	0.21495963	0.18756676
6263	0.75665293E-01	-0.22550722E-01	-0.13356795	0.20923325	0.18141827
7001	0.76162598E-01	-0.62353863E-02	-0.12662210	0.20278469	0.17977082
1780	0.28687377E-01	-0.32237796E-01	-0.15238211	0.18106949	0.15962617
6651	-0.47752751E-01	-0.99192017E-01	-0.21196969	0.16421694	0.14548541
1779	0.17890785E-01	-0.60338253E-01	-0.14286711	0.16075790	0.14211946

5.2 Pure Tensile Load

This section presents the 3-D results for the pure tensile load - Case 1. A free body diagram for this load case is illustrated in Figure 3-1. Five separate load cases were actually analyzed to investigate the effect of several parameters and to calibrate the model with the Goodyear test results.

Table 5-8 summarizes the significant results of the five tensile load cases. Case 1.5 is the final tensile case and is considered the best model simulation of the track shoe. Detailed stress and displacement plots for Case 1.5 are presented later in this section. But first, the significant findings of Table 5-8 will be discussed.

A load of 36,000 lbs. per shoe (same as Goodyear test) was assumed for all tensile cases. The first approximation rubber properties ($E = 20 \times 10^6$ psi and $\nu = .49$) as developed in Appendix B were assumed for Cases 1.1 and 1.2. The only difference between the first two cases is the type of pin support at the outside pin connector. Figures 5-1 and 5-2 show displacement plots for the simple support and clamped support, respectively. There is a significant difference in both displacements and stresses between these two cases. Case 1.2, the clamped support, is considered to be the more realistic representation of the pin connector.

Reviewing the stress results for Cases 1.1 and 1.2, one important and sig-

nificant observation regarding the rubber stresses was made. Although the maximum stress intensity in the rubber is only 4218 psi for Case 1.1, the hydrostatic stress component is very high. For example, the three principal stresses at node 506 in the rubber are SIG1 = 13,907 psi, SIG2 = 11,321 psi, and SIG3 = 9689 psi. This hydrostatic stress state, where the three normal stresses are nearly equal, could cause a problem in a material with a very large Poisson's ratio, such as, rubber.

From the theory of elasticity, the relation between volume expansion and the sum of the three normal stresses can be derived from Hooke's law and is:

$$e = \frac{(1-2\nu)\,\theta}{E}$$

where: $e = \varepsilon_x + \varepsilon_y + \varepsilon_z$

$\theta = \sigma_x + \sigma_y + \sigma_z$

For a uniform hydrostatic stress state:

$\sigma_x = \sigma_y = \sigma_z = \sigma_o$, and

$$e = \frac{3(1-2\nu)\,\sigma_o}{E}$$

For an incompressible material, ν is 1/2 and thus the unit volume expansion e is zero. Therefore, the element will not distort for any value of E and the material will act like a rigid cube.

In our case, there is a large hydrostatic stress component and a very small

rubber displacement. This hydrostatic stress in the rubber is modeling induced, however. Since the rubber is only one element in width, it cannot distort because the nodal displacements are essentially fixed. One side of the rubber is connected to relatively stiff steel and the other side is connected to the relatively stiff aluminum. One way to eliminate this problem is to put more rows of rubber elements between the steel and aluminum and this will permit the rubber to distort. This action was considered too costly because of the large number of additional elements needed and therefore was not taken. Additionally, actual rubber stresses are not significant for this class of problems.

The manner selected to eliminate this modeling induced rigidity problem is to set the Poisson's ratio of rubber equal to zero. This essentially makes a series of radial (uniaxial) springs out of the rubber elements. Since the primary purpose of the rubber is to trnasfer load from the shaft to the shoe, this assumption is considered entirely satisfactory for that purpose.

Case 1.3 of Table 5-8 is exactly the same as Case 1.2 except that Poisson's ratio for the rubber was set to zero. There is a significant increase in shaft deflection due to the more flexible rubber model, and the stresses either remain the same or increase.

Cases 1.3, 1.4, and 1.5 are exactly the same except for the rubber modulus. As can be seen, the shaft deflection increases as the rubber modulus decreases. Case 1.4 is an intermediate case and the detailed stress results were not pro-

cessed. The shaft deflection for Case 1.5 is approximately .088" which is nearly equal to the .098" deflection obtained from the Goodyear test. As a result of these tensile load calibration runs, the model as defined by Case 1.5 is considered to be qualified and will be used to make the demonstration load case runs described in Section 3.0.

Displacement and stress contour plots are presented at six cross-sections in the 3-D shoe model. These six cutting planes are illustrated in Figure 5-3. Figures 5-4 and 5-5 show selected nodal points on Planes 1 and 2, respectively. These sketches are used to locate the nodes when the displacements are summarized.

Tables 5-9 to 5-15 show the maximum stress summaries in the seven element types for the pure tensile load case. This data is in the same format as that presented for the uniform temperature case in Section 5.1. Displacements of the shaft and rubber in Plane 1 for this case are summarized in Table 5-16. Note that the minus sign for the relative displacement column means compression and the plus sign means tension. Since the rubber preload is approximately 0.1" and the maximum rubber stretch is only +.079", the rubber preload is still maintained for this loading.

Figures 5-6 to 5-12 show displacement plots at the six cutting planes as shown in Figure 5-3. It should be noted that some of the displacement plots are greatly exaggerated and some of the components appear to overlap. This is only

caused by the large scale factor. Stress contour plots are shown at the same six planes in Figures 5-13 to 5-22. Most of the plots are stress intensity plots; however, on two planes the principal stress plots are also shown.

It should be emphasized that the maximum loads assumed for this load case and the two succeeding load cases are somewhat arbitrary, although the load selected for this case corresponds to the maximum load used in the Goodyear test (Figure B-5). The analytical model is linear and the results can be scaled as long as the rubber preload is maintained in the binocular section.

The stresses presented in the stress summary tables represent peak surface stresses, for the most part, and are not necessarily the controlling parameter for material failure. Generally, membrane and bending stresses on a given section are more related to ductile failures than the peak surface stress. The actual stress evaluation is beyond the scope of work of this current contract. Additionally, the applied loads must be known in order to make a judgment on the structural adequacy of the component.

The stresses calculated in the steel shaft are relatively high (Table 5-9) and are primarily bending stresses at the symmetry plane and at the connector end. The large forces and moments causing these large shaft stresses are being reacted by the connectors which may also be experiencing high stresses. Additional studies should be performed on the shaft and connector to assess their load-carrying capability.

TABLE 5-8

Summary of the 3-D Model
Tensile Load Studies

Parameters	Case 1.1	Case 1.2	Case 1.3	Case 1.4	Case 1.5
Load (lb)	36,000	36,000	36,000	36,000	36,000
Pin Support	Simple	Clamped	Clamped	Clamped	Clamped
Rubber, E (psi)	20,000	20,000	20,000	7,000	4,000
Rubber, ν	.49	.49	0	0	0
Results					
Max UY @ pin	.039"	.015"	.036"	.062"	.088"
SI, Shaft (1)*	121,297 (N782)**	100,213 (N32)	137,880 (N3782)	NOT AVAILABLE	164,713 (N182)
SI, Rubber (2)	4,218 (N506)	2,422 (N506)	3,321 (N481)		1,814 (N481)
SI, Binocular (3)	43,690 (N506)	27,632 (N3523)	27,549 (N3500)		27,298 (N3523)
SI, End plate (4)	17,872 (N4657)	21,637 (N4657)	26,324 (N4644)		30,150 (N4644)
SI, Rib (5)	12,864 (N1489)	4,590 (N2689)	4,981 (N1489)		10,730 (N1489)
SI, Web (6)	10,043 (N1031)	9,542 (N6307)	19,648 (N6413)		28,122 (N6413)
SI, Fillet (7)	10,062 (N4676)	11,212 (N4676)	11,100 (N6306)		12,026 (N6306)

*Element Types - See Figure 2-9 for identification

**Node Numbers - See Figures 2-11 to 2-17 for locations

TABLE 5-9
Maximum Stress Summary
Type 1 - Steel Shaft
Pure Tensile Load - Case 1.5

ERSE FOR LABEL= TYPE FROM 1 TO 1 BY 1.

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
166	-13952.983	-18097.948	-115879.47	101926.40	99918.604
93	115862.18	18099.283	13953.139	101909.04	99900.522
220	-14259.060	-17601.134	-115993.47	101734.41	100105.22
183	115967.13	17603.099	14257.651	101709.48	100078.70
275	-9775.0511	-17783.186	-108658.53	98883.477	95132.540
242	108630.20	17782.281	9774.4670	98855.733	95105.008
82	-9553.2632	-18584.367	-108308.42	98755.159	94563.599
42	108306.33	18584.648	9554.5350	98751.795	94560.689
221	4184.8397	-2534.5909	-94416.927	98611.767	95425.179
182	94390.304	2533.7683	-4198.4100	98588.714	95400.943
167	4129.3246	-2645.6265	-94350.073	98479.398	95272.760
91	94332.216	2644.8924	-4133.2961	98465.512	95257.457
2799	4223.0001	-5412.5338	-92560.260	96783.261	92343.298
2810	92524.836	5408.0102	-4227.5498	96752.386	92312.539
2798	4143.3390	-5579.9128	-92460.698	96604.037	92128.043

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
166	1	45	1	181	31	7	157	182	32	8	158
93	1	45	1	194	44	20	170	195	45	21	171
220	1	45	1	182	32	8	158	183	33	9	159
183	1	45	1	193	43	19	169	194	44	20	170
275	1	45	1	183	33	9	159	184	34	10	160
242	1	45	1	192	42	18	168	193	43	19	169
82	1	45	1	180	30	6	156	181	31	7	157
42	1	45	1	195	45	21	171	196	46	22	172
221	1	45	1	332	182	158	308	333	183	159	309
182	1	45	1	343	193	169	319	344	194	170	320
167	1	45	1	331	181	157	307	332	182	158	308
91	1	45	1	344	194	170	320	345	195	171	321
2799	1	45	1	3782	3632	3608	3758	3783	3633	3609	3759
2810	1	45	1	3793	3643	3619	3769	3794	3644	3620	3770
2798	1	45	1	3781	3631	3607	3757	3782	3632	3608	3758

***** POST1 NODAL STRESS LISTING *****.

NODE	SIG1	SIG2	SIG3	SI	SIGE
182	13602.730	-9859.3919	-151110.68	164713.41	154346.82
194	151070.89	9882.3815	-13600.865	164671.76	154297.15
3782	12505.475	-14334.686	-150408.33	162913.81	151307.87
3794	150338.59	14367.026	-12502.774	162841.37	151225.19
183	12296.048	-9627.8680	-146516.83	158812.88	149104.84
193	146471.53	9646.3978	-12293.681	158765.21	149051.04
181	12102.052	-9429.0015	-146157.53	158259.59	148707.23
195	146135.09	9448.3134	-12101.390	158236.48	148676.79
3783	11334.458	-14132.029	-145834.45	157168.91	146139.73
3793	145763.23	14157.684	-11331.005	157095.03	146058.00
3781	11089.277	-13900.633	-145259.40	156348.68	145502.10
3795	145210.77	13927.771	-11088.333	156299.11	145443.15
32	-29844.855	-41436.959	-184832.04	154987.18	149528.81
44	184794.78	41436.528	29849.257	154946.52	149489.37
33	-27931.851	-39213.106	-178409.42	150477.57	145405.24

REPORT NO.	REV. NO.	PROJECT NO.	BY	DATE	CHEKD. BY	DATE	PAGE
DEAC-TR-120		ALC-85-003					44

TABLE 5-10
Maximum Stress Summary
Type 2 - Rubber Bushing
Pure Tensile Load - Case 1.5

ERSE FOR LABEL= TYPE FROM 2 TO 2 BY

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
169	1548.0089	-2.4047928	-9.1746090	1557.1835	1553.8097
40	1402.9062	-3.3793306	-154.17734	1557.1636	1487.5084
35	1258.2338	-2.6198361	-298.56930	1556.8031	1431.9522
86	1501.5070	-4.0282072	-54.937841	1556.4448	1531.6252
223	1540.4661	-2.7777809	-14.983215	1555.4493	1549.3826
31	1076.7731	-1.9136490	-477.92780	1554.7009	1379.7191
277	1480.5048	-4.2913352	-71.963734	1552.4685	1519.7627
337	1373.0257	-4.0975076	-178.05475	1551.0804	1471.8322
27	871.82903	-1.2384387	-677.91464	1549.7437	1345.7048
400	1225.7801	-3.4509097	-323.79165	1549.5717	1416.8273
475	1048.9927	-2.4973241	-497.54807	1546.5408	1367.9355
24	659.85139	-0.42508191	-881.99416	1541.8455	1339.8539
524	854.98085	-1.2602881	-685.89435	1540.8752	1337.1928
509	657.33598	0.20396502	-875.45503	1532.7910	1331.9252
25	458.32237	0.66993400	-1073.7552	1532.0776	1362.1852

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
169	2	45	2	655	505	481	631	656	506	482	632
40	2	45	2	653	503	479	629	654	504	480	630
35	2	45	2	652	502	478	628	653	503	479	629
86	2	45	2	654	504	480	630	655	505	481	631
223	2	45	2	656	506	482	632	657	507	483	633
31	2	45	2	651	501	477	627	652	502	478	628
277	2	45	2	657	507	483	633	658	508	484	634
337	2	45	2	658	508	484	634	659	509	485	635
27	2	45	2	650	500	476	626	651	501	477	627
400	2	45	2	659	509	485	635	660	510	486	636
475	2	45	2	660	510	486	636	661	511	487	637
24	2	45	2	673	523	499	649	650	500	476	626
524	2	45	2	661	511	487	637	662	512	488	638
509	2	45	2	662	512	488	638	663	513	489	639
25	2	45	2	672	522	498	648	673	523	499	649

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
481	1757.2775	-8.3263357	-57.092423	1814.3699	1790.8161
482	1780.2937	-11.289583	-33.800216	1814.0939	1802.9548
483	1737.4880	-7.5408543	-71.545519	1809.0335	1778.4128
480	1669.1283	-7.2207347	-133.10903	1802.2374	1744.0788
484	1634.1161	-7.3876283	-157.84102	1791.9571	1723.2635
479	1522.4712	-6.1982585	-261.57566	1784.0469	1673.3585
485	1480.0789	-6.2870233	-292.60882	1772.6877	1650.5781
478	1328.4596	-4.4513176	-437.65686	1766.1165	1596.6954
486	1288.1063	-4.5457096	-467.29810	1755.4044	1578.0607
495	53.929702	8.3203543	-1697.8717	1751.8014	1729.7451
477	1101.6366	-2.3507778	-649.83377	1751.4693	1535.8902
496	125.28188	7.2648169	-1623.0243	1748.3062	1693.6599
494	31.974133	11.268108	-1715.7513	1747.7254	1737.4750
493	67.220143	7.5086777	-1677.7552	1744.9754	1716.3625
632	1708.3516	-10.185857	-34.028831	1742.3804	1730.5917

REPORT NO.	REV. NO.	PROJECT NO.	BY	DATE	CHEKD. BY	DATE	PAGE
DEAC-TR-120		ALC-85-003					45

TABLE 5-11
Maximum Stress Summary
Type 3 - Shoe Binocular
Pure Tensile Load - Case 1.5

ERSE FOR LABEL= TYPE FROM 3 TO 3 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
2423	16906.016	153.39400	-1915.0585	18821.075	17876.824
655	15673.986	659.06406	-2766.4901	18440.476	16988.724
2516	18293.433	1059.2793	354.16535	17939.268	17597.309
2436	16150.052	515.91880	-1474.8272	17624.879	16718.636
656	14931.725	956.83715	-2488.3117	17420.036	15978.489
654	13648.572	470.06305	-2926.0519	16574.624	15164.512
2295	14107.554	841.54255	-2160.3182	16267.872	14994.030
748	12426.740	565.48528	-3705.6713	16132.411	14477.341
2512	15846.632	1451.5396	-99.928713	15946.560	15230.209
629	12600.083	416.92266	-3202.7778	15802.861	14339.840
749	9741.1577	62.302817	-5443.9492	15185.107	13315.151
746	13192.974	808.06108	-1939.9672	15132.942	13963.231
2624	15994.559	1113.3538	900.08242	15094.477	14988.979
2290	11811.794	751.08170	-2975.8740	14787.668	13321.124
630	8971.0338	-384.86630	-5680.8139	14651.848	12850.225

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
2423	3	45	3	3573	3423	3399	3549	3574	3424	3400	3550
655	3	45	3	1174	1024	1000	1150	1175	1025	1001	1151
2516	3	45	3	3571	3421	3373	3523	3548	3398	3350	3500
2436	3	45	3	3548	3398	3350	3500	3549	3399	3351	3501
656	3	45	3	1175	1025	1001	1151	1176	1026	1002	1152
654	3	45	3	1173	1023	999	1149	1174	1024	1000	1150
2295	3	45	3	3398	3248	3200	3350	3399	3249	3201	3351
748	3	45	3	1298	1148	1100	1250	1299	1149	1101	1251
2512	3	45	3	3421	3271	3223	3373	3398	3248	3200	3350
629	3	45	3	1148	998	950	1100	1149	999	951	1101
749	3	45	3	1299	1149	1101	1251	1300	1150	1102	1252
746	3	45	3	1321	1171	1123	1273	1298	1148	1100	1250
2624	3	45	3	3570	3420	3372	3522	3571	3421	3373	3523
2290	3	45	3	3248	3098	3050	3200	3249	3099	3051	3201
630	3	45	3	1149	999	951	1101	1150	1000	952	1102

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
3623	27327.342	1198.1455	29.434257	27297.908	26733.883
3500	25092.608	632.33778	-1903.0273	26995.636	25827.264
3373	24649.559	1742.7145	184.95115	24464.608	23737.232
3350	22198.064	769.95517	-1089.5073	23287.572	22419.298
3522	22924.799	1613.7490	178.36685	22746.432	22064.045
3501	16982.313	233.13905	-4629.6526	21611.965	19670.232
523	21195.289	954.77226	-241.58679	21436.875	20864.720
673	20980.596	1556.6970	-0.37815808	20980.974	20253.037
3200	19410.205	929.09456	-1363.6136	20773.818	19729.157
3372	20839.832	2371.8987	77.457131	20762.375	19724.418
522	20554.770	1363.5342	67.539014	20487.231	19870.962
3573	17986.943	-1096.7566	-2236.4395	20223.383	19686.773
3223	20142.951	1927.9459	6.5223588	20136.429	19275.365
823	20207.600	2129.3359	156.77114	20050.828	19147.384
672	19894.864	2040.6265	-17.069574	19911.934	18971.468

TABLE 5-12
Maximum Stress Summary
Type 4 - Shoe End Plates
Pure Tensile Load - Case 1.5

ERSE FOR LABEL= TYPE FROM 4 TO 4 BY

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
2422	24393.849	372.87827	128.23348	24265.616	24144.223
2425	25066.945	2232.1935	1290.9305	23776.015	23319.635
2216	22847.578	625.52482	-497.42886	23345.007	22804.276
2543	22167.544	110.66606	-154.47976	22322.024	22190.639
2206	16526.091	-973.82679	-4831.1563	21357.248	19713.677
2424	20732.745	583.28696	-217.24068	20949.986	20561.413
2545	20530.440	48.410778	-57.107447	20587.548	20534.882
207	20191.171	1392.7528	14.699470	20176.472	19523.964
2215	20787.675	2190.6493	678.87585	20108.799	19397.147
2412	21114.593	1289.0882	1071.2163	20043.377	19935.334
206	16743.526	930.91641	-3100.2205	19843.747	18166.769
201	20581.278	2736.0804	850.20332	19731.075	18858.989
2414	19350.472	56.706707	-305.49606	19655.968	19477.392
2641	19460.575	83.563506	-47.791070	19508.366	19443.022
2725	18933.010	47.667278	-38.453435	18971.464	18928.550

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
2422	4	45	3	4644	4657	4658	4645	4761	4774	4775	4762
2425	4	45	3	4735	4748	3424	3423	4852	4865	3574	3573
2216	4	45	3	4631	4644	4645	3274	4748	4761	4762	3424
2543	4	45	3	4657	4670	4671	4658	4774	4787	4788	4775
2206	4	45	3	3274	4645	4646	3275	3424	4762	4763	3425
2424	4	45	3	4748	4761	4762	3424	4865	4878	4879	3574
2545	4	45	3	4670	4683	4684	4671	4787	4800	4801	4788
207	4	45	3	4248	4261	4262	874	4365	4378	4379	1024
2215	4	45	3	4618	4631	3274	3273	4735	4748	3424	3423
2412	4	45	3	4645	4658	4659	4646	4762	4775	4776	4763
206	4	45	3	874	4262	4263	875	1024	4379	4380	1025
201	4	45	3	4235	4248	874	873	4352	4365	1024	1023
2414	4	45	3	4658	4671	4672	4659	4775	4788	4789	4776
2641	4	45	3	4683	4696	4697	4684	4800	4813	4814	4801
2725	4	45	3	4696	4709	4710	4697	4813	4826	4827	4814

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
4644	29604.067	368.61149	-546.04945	30150.117	29703.308
4657	28149.801	308.93705	-171.43323	28321.235	28084.201
4658	25552.029	126.64243	-350.22398	25902.253	25667.253
4645	25297.622	1103.1575	-153.92343	25451.545	24849.915
4670	25383.275	67.794665	20.484388	25362.790	25339.173
4761	24466.606	142.95583	-560.89419	25027.500	24683.624
4852	23055.779	434.75206	-1801.6587	24857.438	23832.818
4378	23529.830	-72.932219	-784.45698	24314.287	23968.610
4865	20557.733	-1736.4524	-3659.0851	24216.818	23334.653
4683	23736.510	226.11354	55.790118	23680.720	23596.033
4365	20008.888	-795.16213	-3644.9410	23653.829	22406.564
4671	23505.371	417.65747	88.690536	23416.681	23255.039
1025	23741.413	4774.4425	334.52872	23406.884	21533.158
4659	22900.475	655.14898	-6.5856583	22907.061	22586.276
4748	19300.963	-1545.4122	-3511.9095	22812.873	21928.034

TABLE 5-13
Maximum Stress Summary
Type 5 - Shoe Rib and Wall
Pure Tensile Load - Case 1.5

ERSE FOR LABEL= TYPE FROM 5 TO 5 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1048	8167.5958	1815.3907	-1302.8592	9470.4550	8359.5308
1679	8148.4326	2375.6339	-1199.0680	9347.5006	8169.4390
548	68.670680	-777.22636	-6790.5301	6859.2007	6477.0082
1055	4644.3050	-357.39820	-1269.4895	5913.7945	5514.6129
2175	124.39383	-496.42752	-5412.9080	5537.3018	5254.4700
2152	1524.7572	-1403.2858	-3837.8637	5362.6209	4650.7155
549	706.31550	-543.36092	-4528.4646	5234.7800	4735.2753
2334	1586.9697	-257.02357	-3592.6670	5179.6366	4547.2774
539	1455.0210	-155.04582	-3662.6216	5117.6426	4532.4203
541	1044.3206	-1382.0432	-3998.5798	5042.9004	4368.3149
566	1616.7221	-809.23924	-3373.2139	4989.9360	4321.9623
1175	3412.4346	370.04285	-1478.6950	4891.1296	4277.6820
2020	1849.1093	-863.64348	-3010.8420	4859.9513	4218.3300
1307	2500.3402	343.83104	-2063.0575	4563.3977	3954.0007
494	1953.6396	-40.290033	-2494.3286	4447.9683	3858.9171

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1048	5	45	3	1485	1484	5218	5218	5065	5065	5065	5065
1679	5	45	3	2685	2684	5242	5242	5085	5085	5085	5085
548	5	45	3	5254	4260	4143	4143	5154	4259	4142	4142
1055	5	45	3	5519	1488	1489	1489	5522	1638	1639	1639
2175	5	45	3	5274	4643	4760	4760	5174	4642	4759	4759
2152	5	45	3	5170	5172	5173	5171	3434	3284	3283	3433
549	5	45	3	5257	5254	5253	5253	5157	5154	5153	5153
2334	5	45	3	4876	5170	5171	5171	4875	3434	3433	3433
539	5	45	3	4025	5150	5151	5151	4024	734	733	733
541	5	45	3	5150	5152	5153	5151	734	884	883	733
566	5	45	3	5152	5155	5156	5156	884	1035	1034	1034
1175	5	45	3	5522	1638	1639	1639	5525	1788	1789	1789
2020	5	45	3	5172	5175	5176	5176	3284	3135	3134	3134
1307	5	45	3	5525	1788	1789	1789	5528	1938	1939	1939
494	5	45	3	5157	5154	5153	5153	1033	882	883	883

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1489	4578.7542	-1799.0408	-6151.7452	10730.499	9347.8854
4259	-2481.2300	-3673.7464	-11729.978	9248.7482	8735.1069
4260	21.295487	-468.25717	-8413.9382	8435.2337	8201.4229
3434	314.34441	-2995.8025	-7767.8516	8082.1960	7261.5842
4642	-2517.4254	-3194.6711	-10551.738	8034.3126	7744.6812
734	-138.95797	-2687.7764	-7917.3068	7778.3489	7025.5870
2689	3855.6584	-905.66868	-3903.5449	7759.2032	6777.2683
4758	10051.633	4446.9477	2663.9679	7387.6650	6815.1204
4141	9918.5938	4431.2154	2570.1683	7348.4255	6705.6328
5254	1046.5085	-564.43491	-6079.3188	7125.8272	6519.0680
4643	27.839460	-264.96063	-6834.5129	6862.3523	6720.7376
3284	1279.3696	-2261.4768	-5255.0761	6534.4457	5673.5597
884	1136.8307	-2238.2616	-5167.1211	6303.9518	5467.1699
4143	753.11455	-700.88030	-5538.6887	6291.8032	5729.8299
1639	3570.9121	-476.38388	-2320.1151	5891.0272	5220.3958

TABLE 5-14
Maximum Stress Summary
Type 6 - Shoe Web
Pure Tensile Load - Case 1.5

ERSE FOR LABEL= TYPE FROM 6 TO 6 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1530	19308.196	2214.9655	-214.90306	19603.099	18500.182
1486	17204.974	1722.2130	-296.40454	17501.379	16584.465
1485	17136.824	1611.1707	877.68511	16258.139	15904.086
1459	16054.527	1526.4065	521.27242	15533.255	15055.873
1482	15978.775	2601.2588	515.33383	15463.441	14533.187
1528	15413.293	2600.7963	2.5130214	15410.780	14289.914
1526	13887.472	2277.9964	-706.69959	14594.171	13354.366
1460	13159.608	1996.3187	-1328.8302	14488.438	13145.161
1461	13303.570	889.73518	-541.99105	13845.561	13188.114
1463	13603.048	1576.7721	-3.1487649	13606.197	12889.067
1449	11725.200	-130.45226	-1130.6612	12855.862	12386.083
1444	13097.790	1917.5108	833.60540	12264.185	11759.756
1464	12780.423	1700.2917	522.41877	12258.004	11713.568
938	8174.1961	222.21621	-3977.4195	12151.616	10689.544
1318	9834.6686	28.444847	-1610.9479	11445.616	10720.349

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1530	6	45	3	6212	6225	6226	6213	6412	6425	6426	6413
1486	6	45	3	6211	6224	6225	6212	6411	6424	6425	6412
1485	6	45	3	6224	6237	6238	6225	6424	6437	6438	6425
1459	6	45	3	6223	6236	6237	6224	6423	6436	6437	6424
1482	6	45	3	6238	6438	6260	6260	6237	6437	6259	6259
1528	6	45	3	6225	6238	6239	6226	6425	6438	6439	6426
1526	6	45	3	6239	6439	6261	6261	6238	6438	6260	6260
1460	6	45	3	6236	6257	6237	6237	6436	6457	6437	6437
1461	6	45	3	6210	6223	6224	6211	6410	6423	6424	6411
1463	6	45	3	6237	6437	6259	6259	6257	6457	6258	6258
1449	6	45	3	6257	6457	6258	6258	6255	6455	6256	6256
1444	6	45	3	6222	6235	6236	6223	6422	6435	6436	6423
1464	6	45	3	6436	6457	6437	6437	6636	6657	6637	6637
938	6	45	3	6217	6230	6231	6218	6417	6430	6431	6418
1318	6	45	3	6255	6455	6256	6256	6253	6453	6254	6254

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
6413	28896.304	3728.7555	774.34971	28121.954	26767.315
6412	27412.309	3312.9525	845.01346	26567.295	25423.796
6213	23142.544	2525.8963	739.91452	22402.630	21565.203
6637	16059.464	1111.5789	-6342.8266	22402.291	19759.429
6411	23017.993	2640.1229	1169.6127	21848.380	21151.578
6212	21735.817	2087.5667	695.10769	21040.709	20380.868
6438	20398.726	3345.3963	942.30718	19456.419	18397.615
6437	19947.054	4094.2846	1224.2246	18722.830	17558.108
6426	17412.138	2861.8597	-97.836200	17509.974	16236.837
6401	17465.888	1249.9825	4.8268811	17461.061	16872.976
6425	16883.758	2271.9615	-559.08486	17442.842	16224.194
6439	18554.347	4032.4685	1233.9485	17320.398	16113.396
6211	17831.415	1606.5577	655.68700	17175.728	16725.932
6457	16234.904	1654.1339	-873.61277	17108.517	16032.829
6402	16836.816	752.53489	-160.65147	16997.468	16559.770

TABLE 5-15
Maximum Stress Summary
Type 7 - Shoe Fillets
Pure Tensile Load - Case 1.5

EMSE FOR LABEL= TYPE FROM 7 TO 7 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1876	4092.6142	607.66191	-6669.9343	10762.549	9511.5916
1858	5656.6646	1582.5761	-5100.1768	10756.841	9406.5674
1888	3622.8408	766.86830	-7101.2083	10724.049	9619.4708
1843	6948.7893	-562.99635	-3559.4047	10508.194	9376.2340
1723	7579.2452	558.61143	-2712.5497	10291.795	N-LB3°k-
1395	8692.8451	2512.6773	-1496.4724	10189.318	8890.7240
1265	8087.4456	-664.94623	-2050.4395	10137.885	9521.0469
1611	7866.4725	1193.6047	-1890.5752	9757.0477	8638.2669
1255	7645.7004	2664.5223	-2061.0863	9706.7867	8407.2951
1546	8079.3086	1723.6013	-1032.0827	9111.3913	8093.4004
1394	8153.3012	1990.4782	-271.76447	8425.0657	7552.4784
1994	7588.7907	1231.0066	-821.18517	8409.9758	7594.7548
1518	7795.1466	1864.9714	-503.20266	8298.3493	7403.9796
1983	5397.7273	169.41128	-2883.5954	8281.3227	7253.8419
2010	4091.0990	-738.17154	-4057.9396	8149.0386	7097.5187

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1876	7	45	3	6307	7017	6313	6313	6308	7018	6314	6314
1858	7	45	3	6306	7016	6312	6312	6307	7017	6313	6313
1888	7	45	3	6308	7018	6314	6314	6309	7019	6315	6315
1843	7	45	3	6306	6305	7008	7008	7016	6311	7009	7009
1723	7	45	3	6300	6299	7007	7007	6306	6305	7008	7008
1395	7	45	3	6263	6264	7001	7001	6254	6254	6254	6254
1265	7	45	3	6451	6453	6254	6254	7001	7001	7001	7001
1611	7	45	3	6294	6293	7006	7006	6300	6299	7007	7007
1255	7	45	3	1780	6451	1779	1779	6651	6651	6651	6651
1546	7	45	3	6288	6287	7005	7005	6294	6293	7006	7006
1394	7	45	3	6264	6263	7001	7001	6270	6269	7002	7002
1994	7	45	3	3279	3280	4663	4663	7009	7009	7009	7009
1518	7	45	3	6282	6281	7004	7004	6288	6287	7005	7005
1983	7	45	3	3279	3130	3129	3129	7009	7009	7009	7009
2010	7	45	3	6312	4677	4676	7016	6313	4690	4689	7017

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
6306	7887.7382	1054.7921	-4138.7004	12026.439	10502.406
6300	7234.8242	1806.8669	-4471.3966	11706.221	10149.050
6307	5896.5835	1045.2211	-5701.3081	11597.892	10082.530
6308	4756.4867	1287.2297	-6451.1019	11207.589	9938.5670
2829	5571.7567	-1149.2347	-5570.4500	11142.207	9725.9089
6309	4199.6830	1001.0788	-6939.9783	11139.661	9934.3724
2679	5971.0717	-506.34892	-4915.2795	10886.351	9484.5855
6294	7880.3536	2276.0769	-2769.6720	10650.026	9228.4584
7017	5166.0929	305.03275	-5333.4080	10499.501	9132.4280
7016	6336.7811	625.50963	-4075.1429	10411.924	9065.1928
6254	8390.1454	823.86554	-1773.4560	10163.601	8205.8855
7018	4429.1187	568.20582	-5727.5291	10156.648	8925.3628
6453	8087.4456	-664.94623	-2050.4395	10137.885	9521.0469
7019	4173.0536	465.55705	-5940.4044	10113.458	8907.1755
2529	6023.3840	-320.23198	-3894.7878	9918.1718	8701.6492

TABLE 5-16
Displacement Summary for Tensile Load Case 1.5

SHAFT DISPLACEMENTS

LOCATION	NODES	ΔY (DISP)
Connector End	32, 44	-.087825
Symmetry Plane	3932, 3944	-.079927

RUBBER DISPLACEMENTS

$NODE_i$	UY_i	$NODE_j$	UY_j	RELATIVE DISPLACEMENT $\Delta = UY_i - UY_j$
494	-.079496	518	-.002833	-.076663
944	-.069547	968	-.003969	-.065578
1994	-.044131	2018	-.006745	-.037386
3044	-.066654	3068	-.004954	-.06170
3494	-.074898	3518	-.004022	-.070876
506	-.000058	482	-.079491	+.079433
956	-.0009104	932	-.069539	+.068629
2006	-.005465	1982	-.044127	+.038662
3056	-.002176	3032	-.066646	+.06447
3506	-.000076	3482	-.074893	+.074817

NOTES: (1) Refer to Figure 5-4 for node locations.
(2) Minus sign on relative displacements (Δ) means compression.

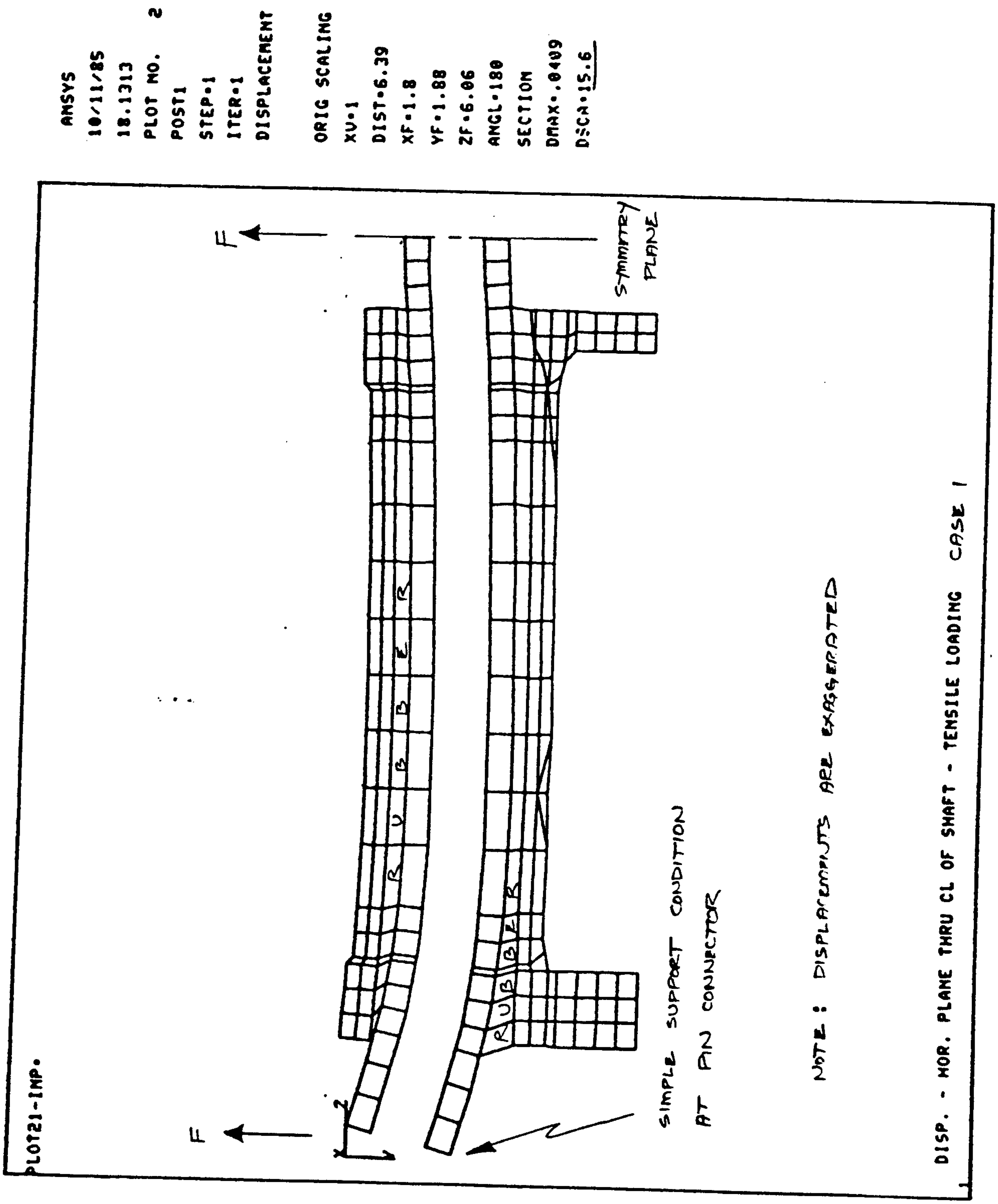


Figure 5-1 - Displacement Plot, Tensile Case 1.1

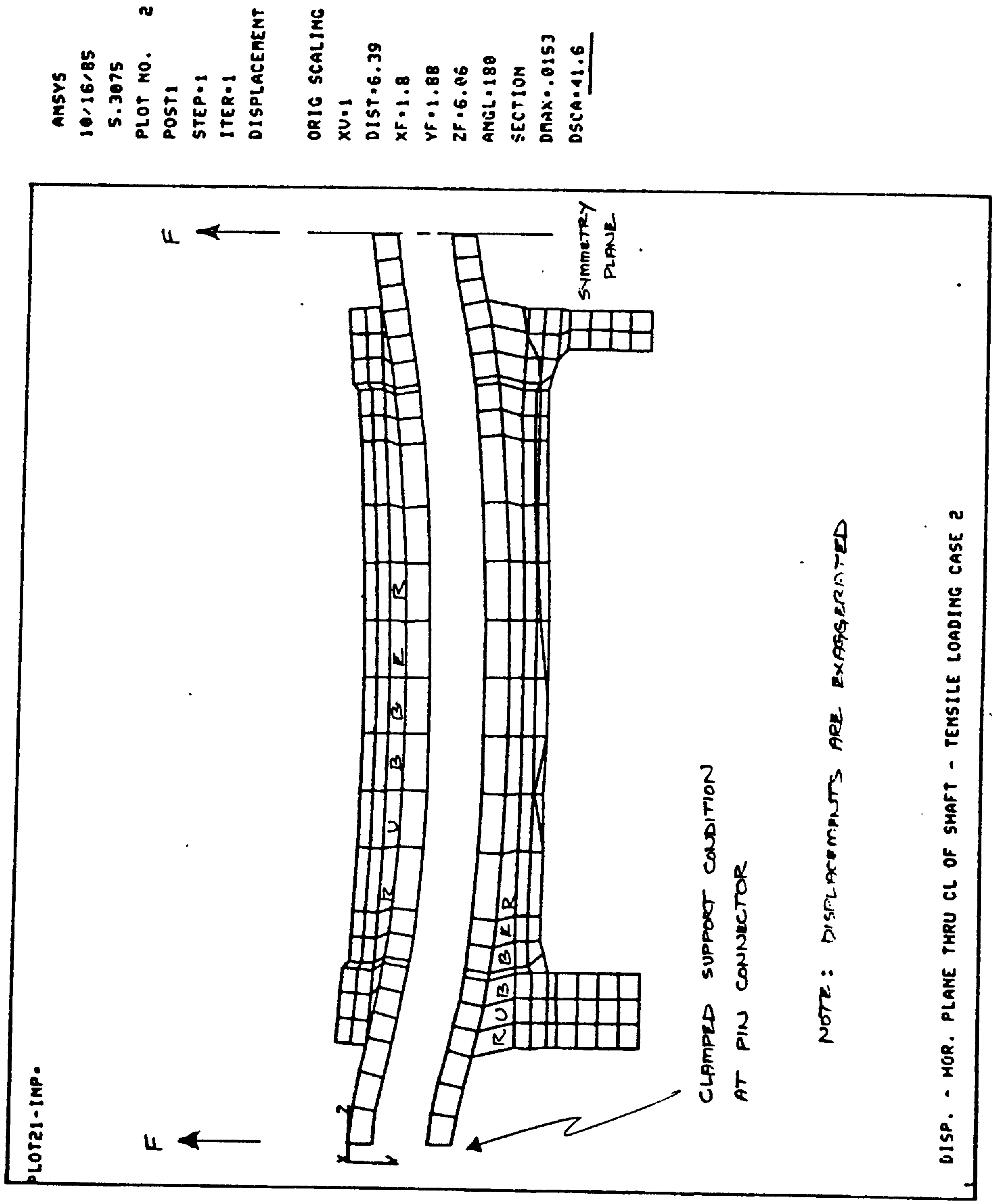


Figure 5-2 - Displacement Plot, Tensile Case 1.2

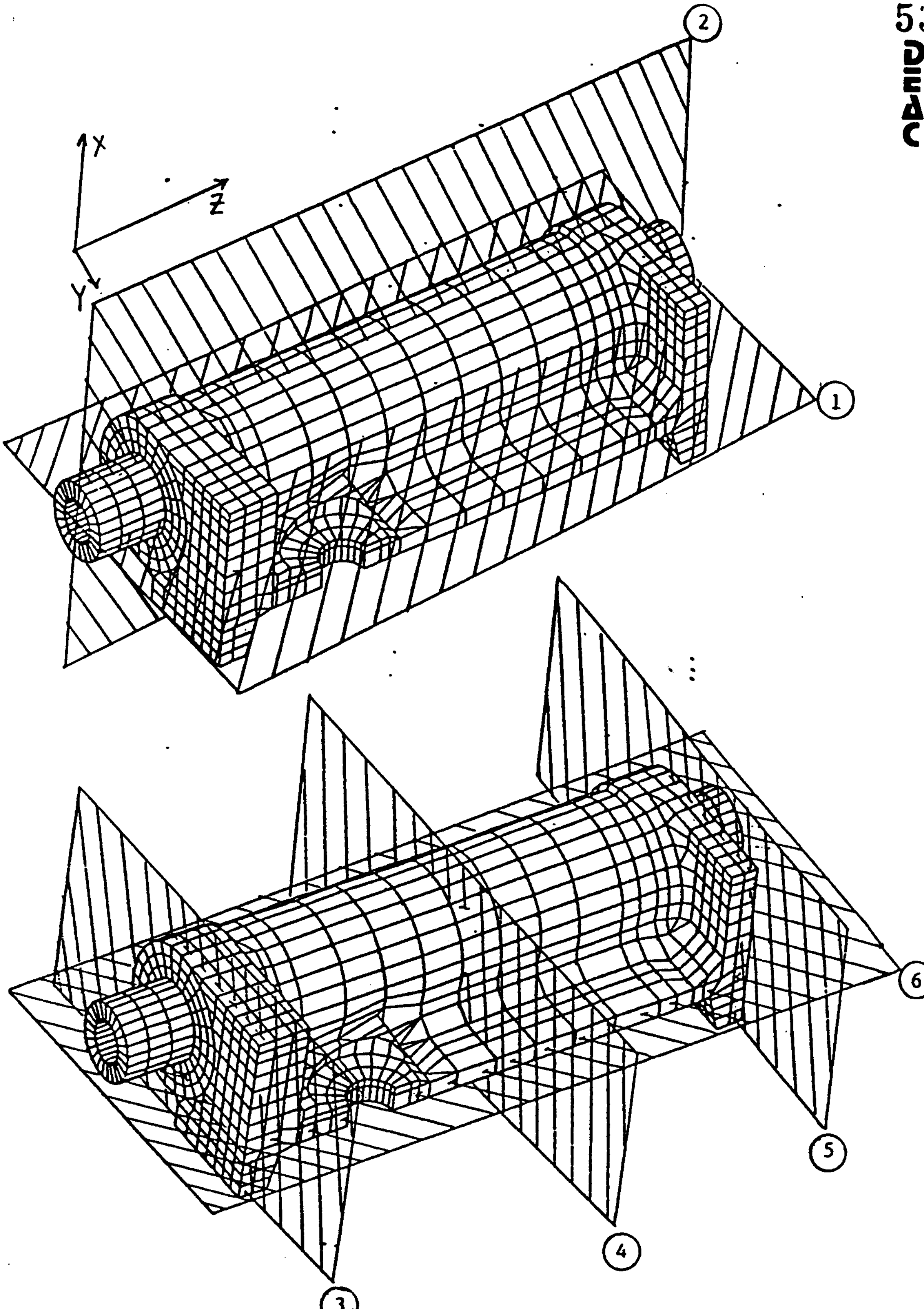


Figure 5-3 - Cutting Planes Used to View Finite Element Results

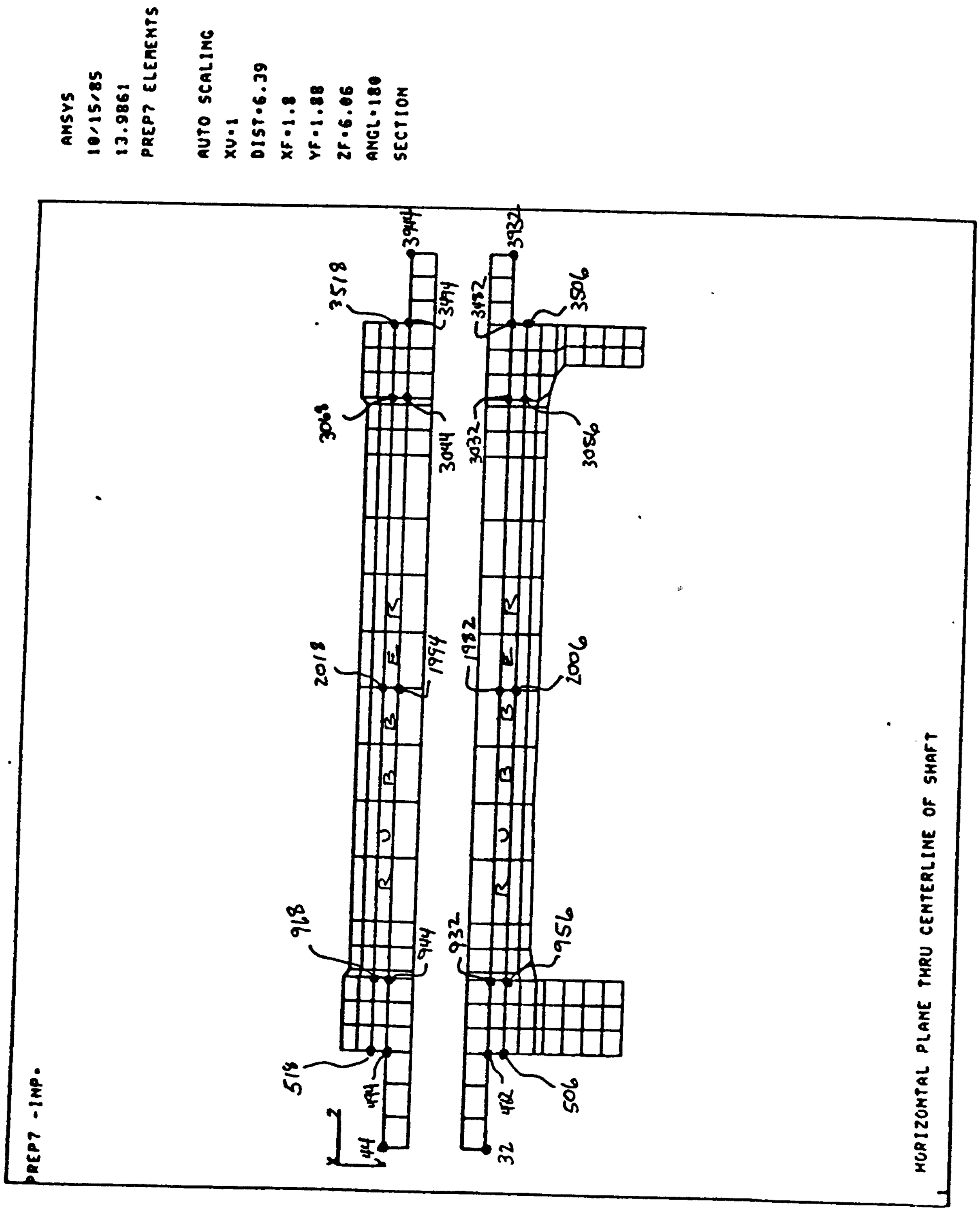


Figure 5-4 - Selected Nodal Points on Plane 1

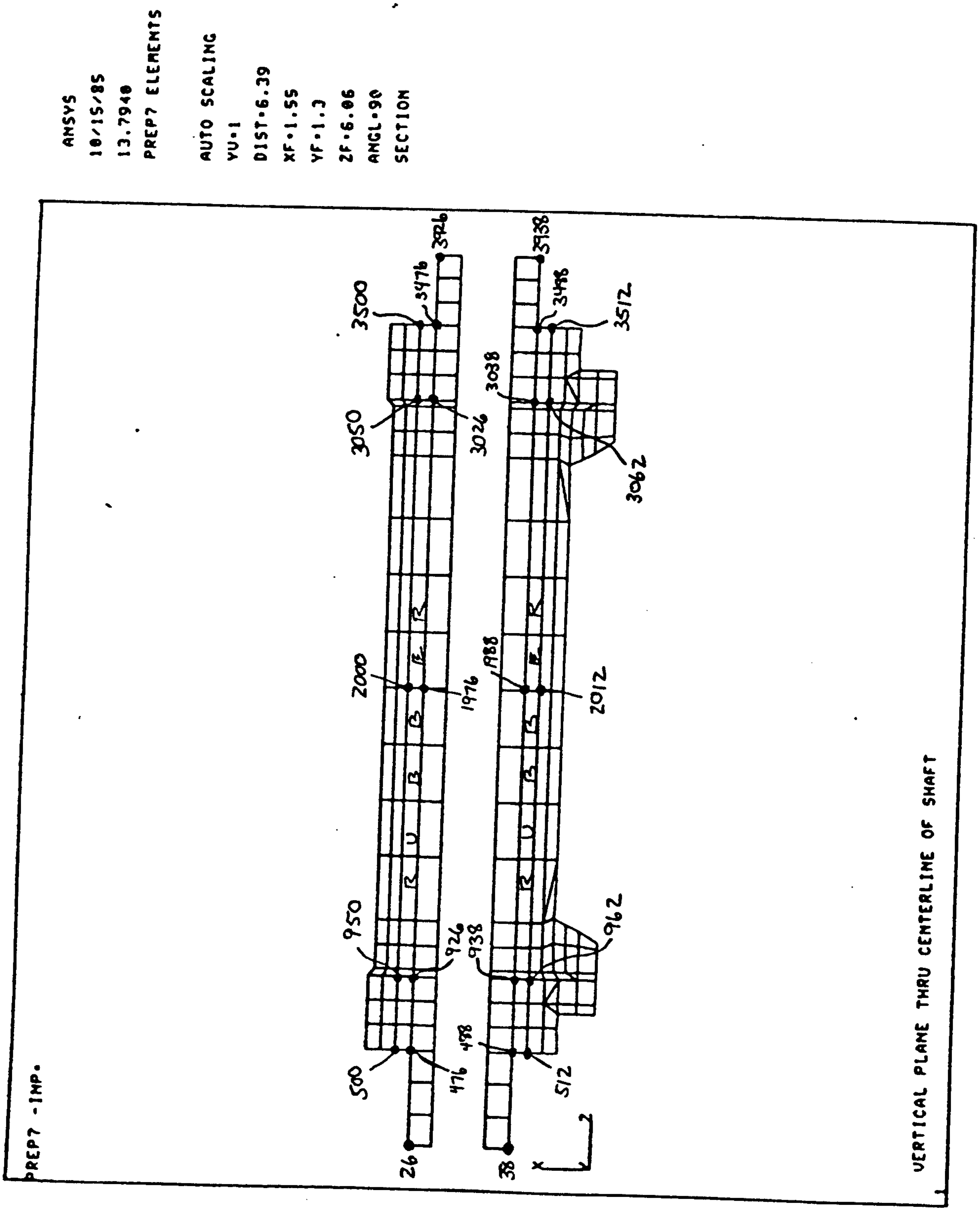


Figure 5-5 - Selected Nodal Points on Plane 2

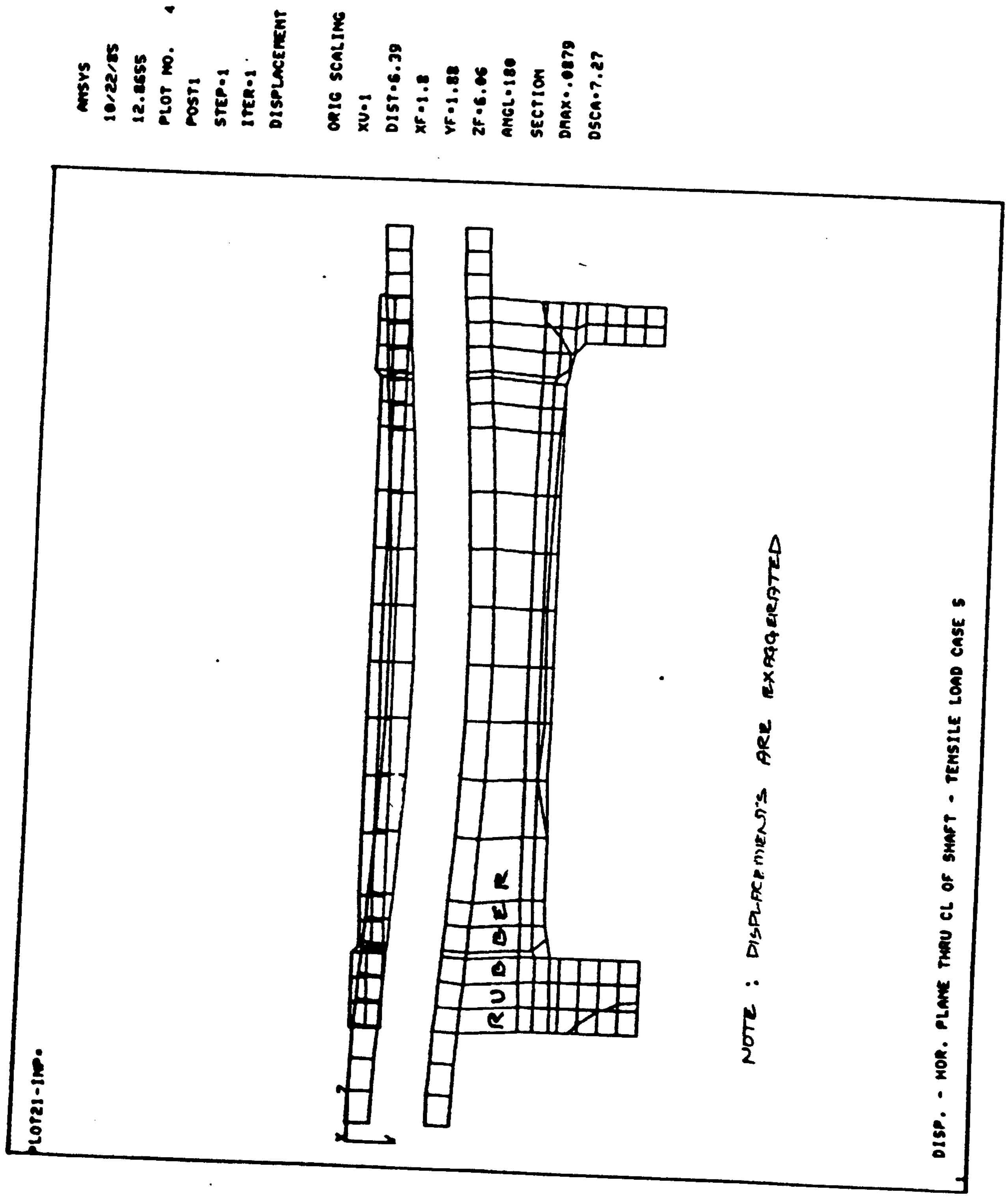


Figure 5-6 - Displacements, Plane 1, Tensile Load Case 1.5
Exaggerated Displacements, Scale = 7.27

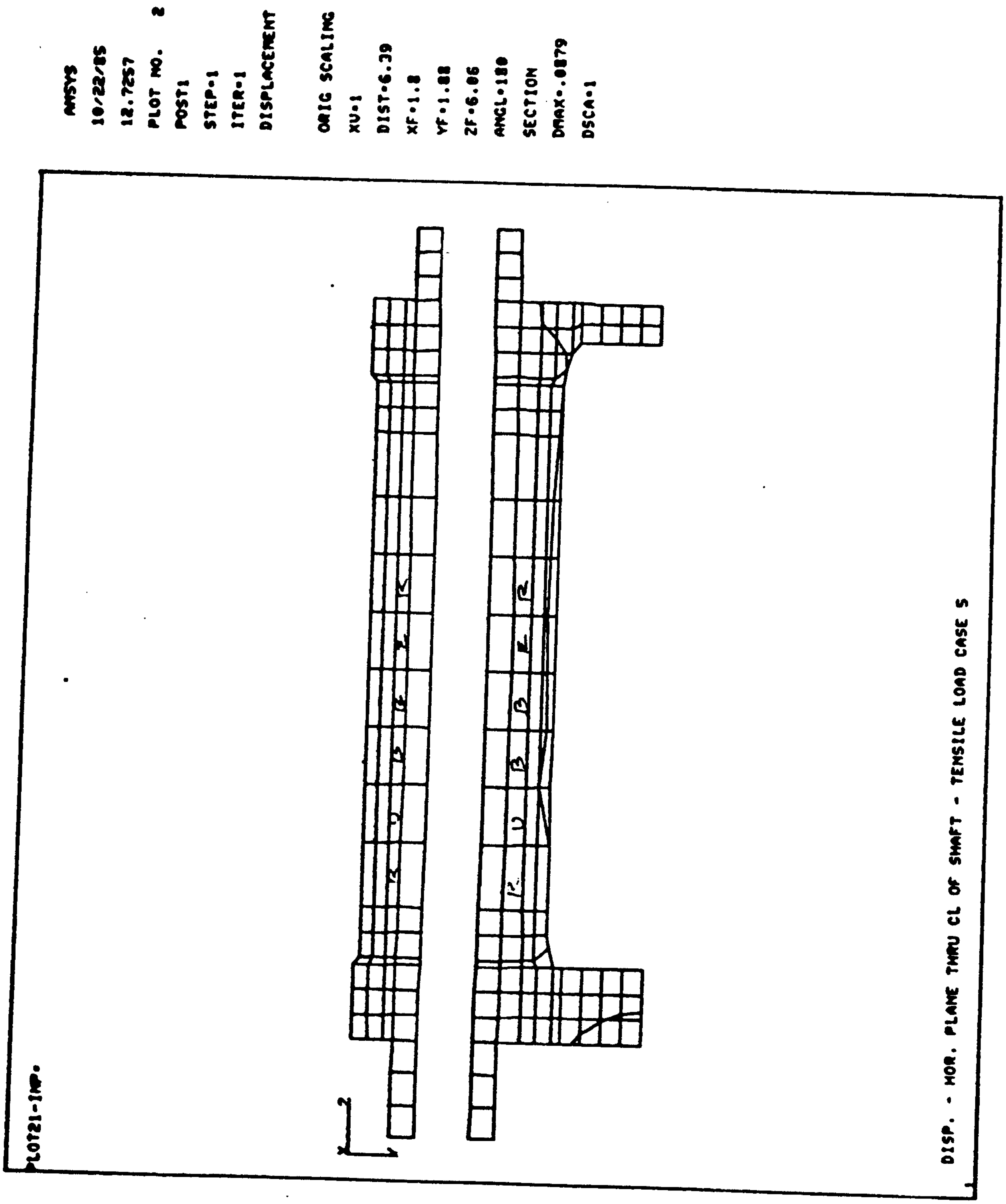


Figure 5-7 - Displacements, Plane 1, Tensile Load Case 1.5
Displacements to Scale, Scale = 1.0

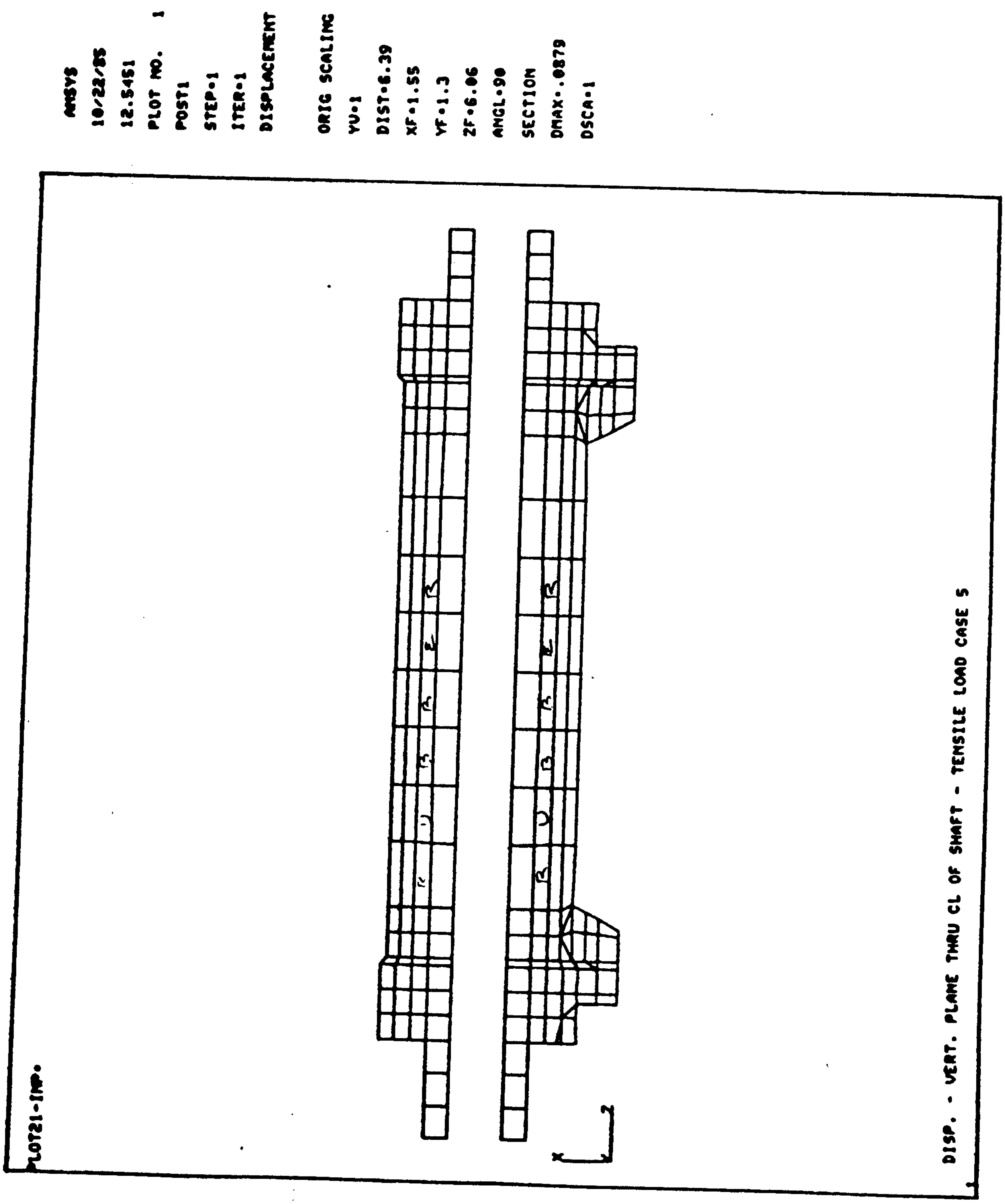


Figure 5-8 - Displacements, Plane 2, Tensile Load Case 1.5

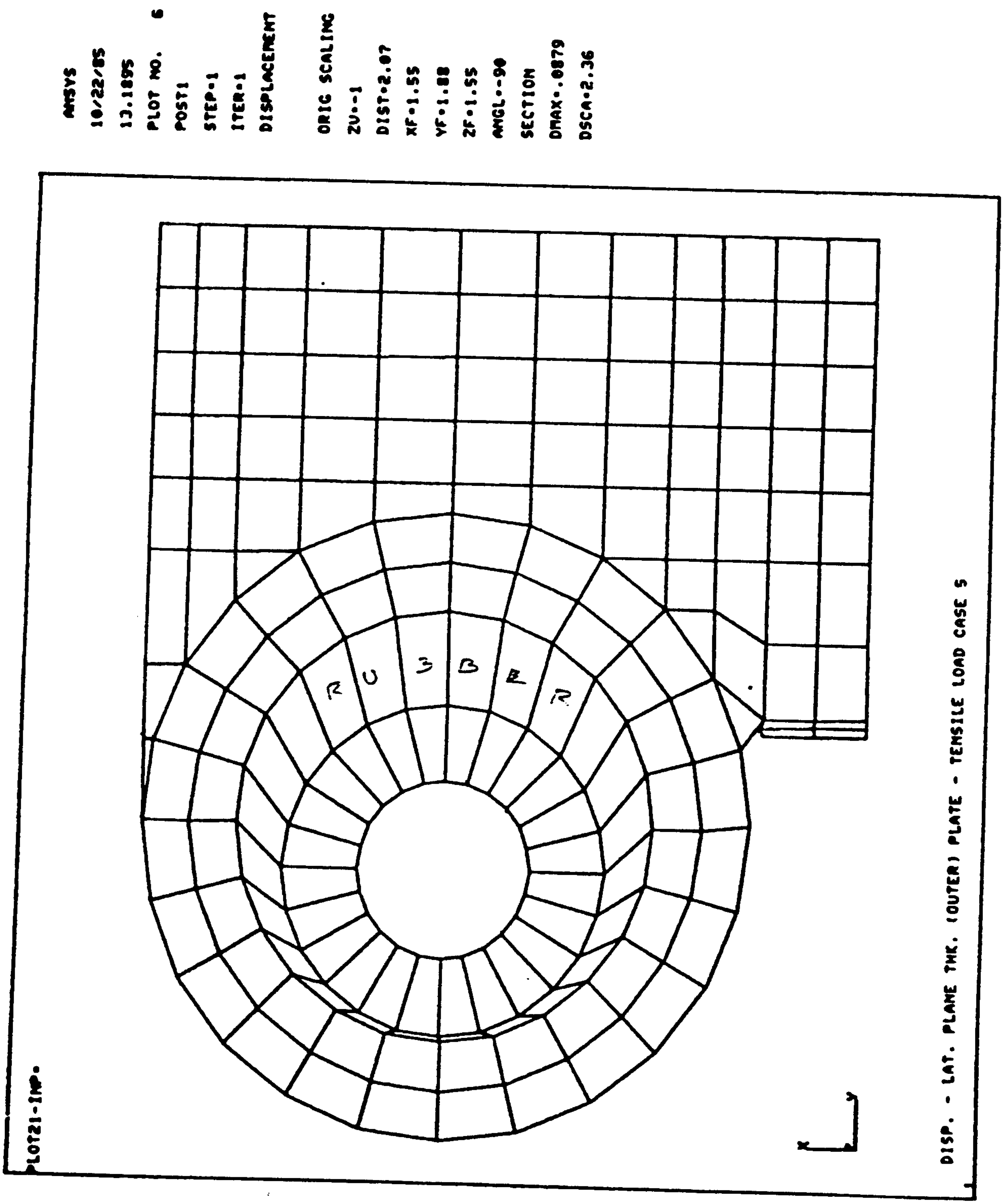


Figure 5-9 - Displacements, Plane 3, Tensile Load Case 1.5

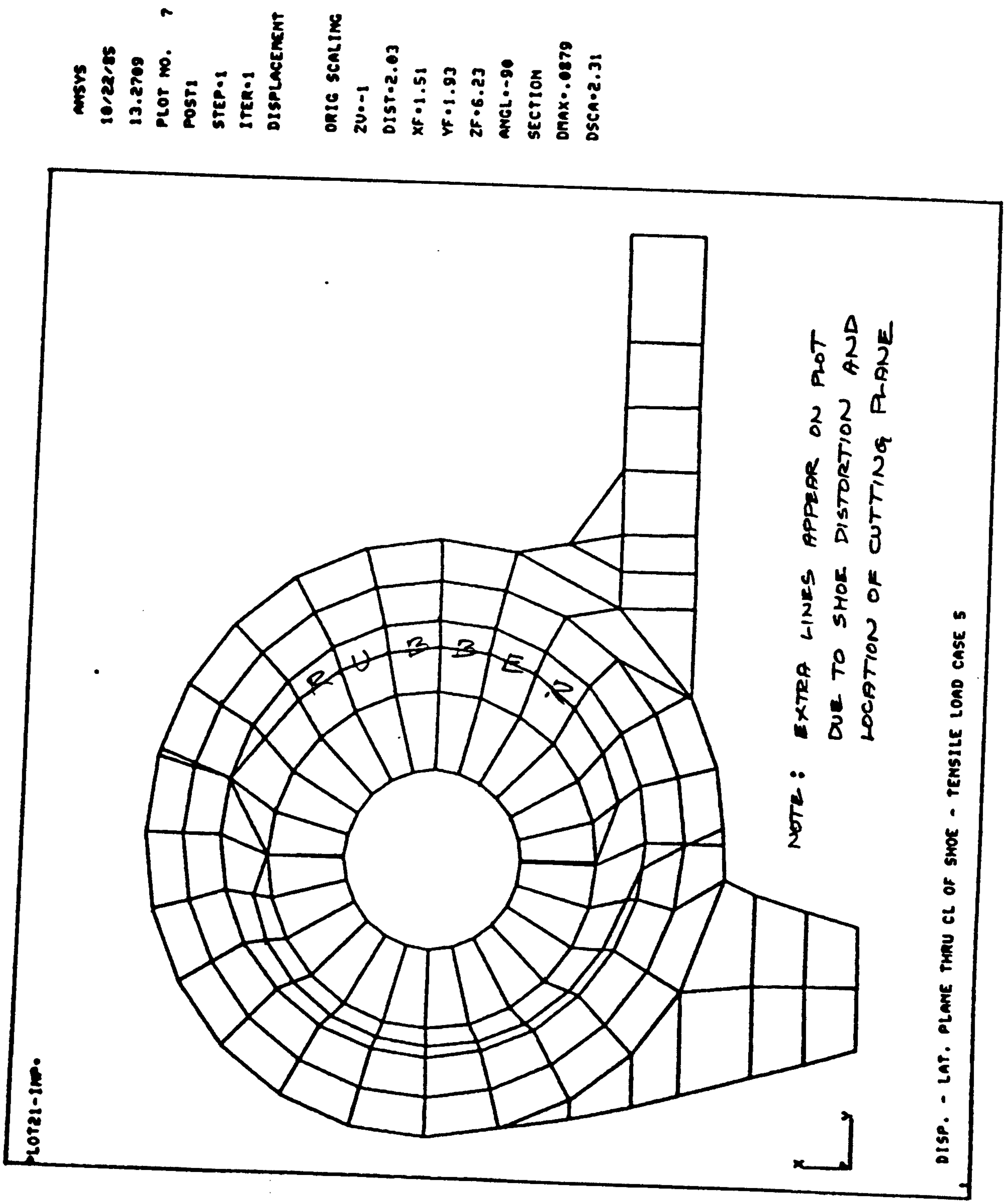


Figure 5-10 - Displacements, Plane 4, Tensile Load Case 1.5

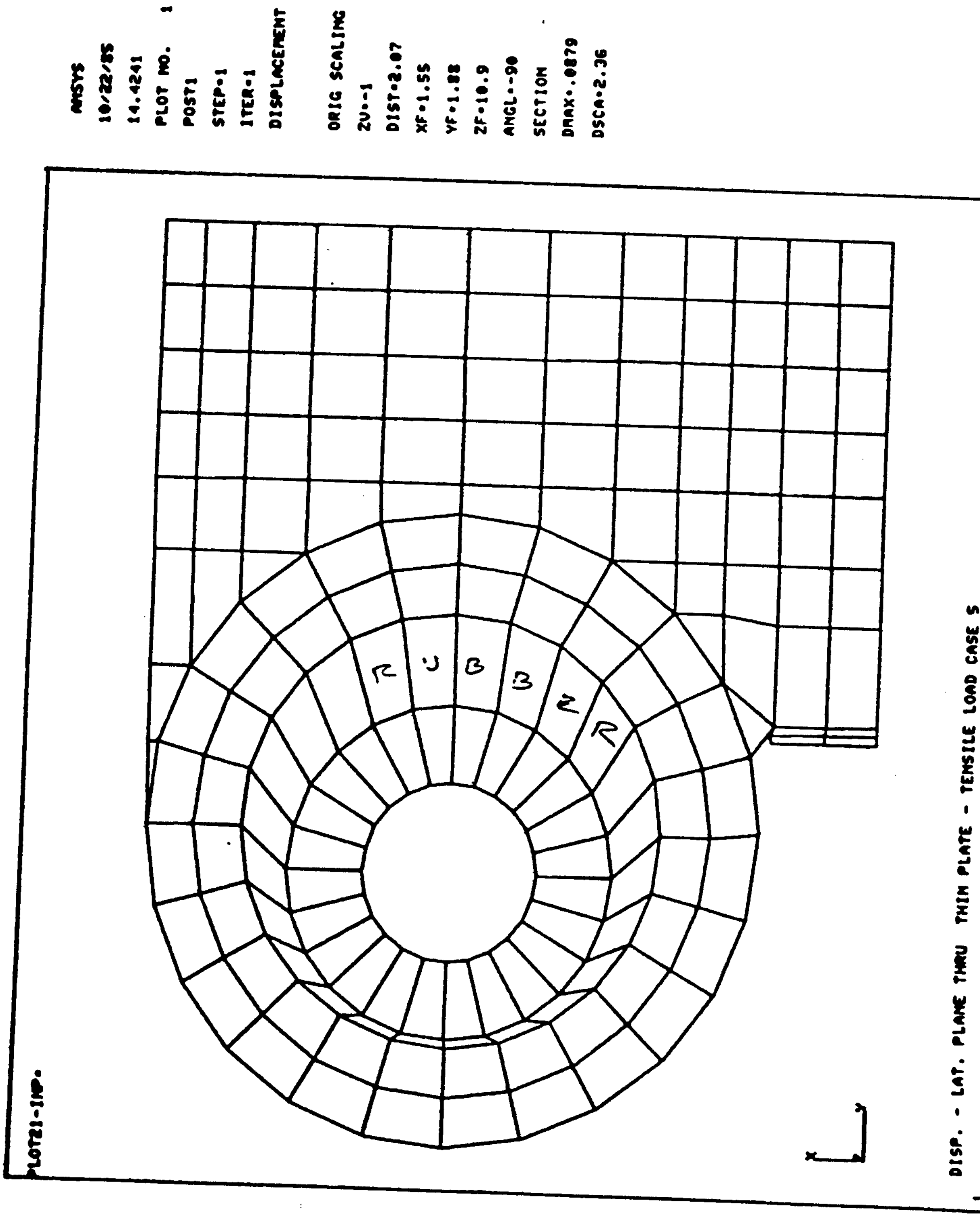


Figure 5-11 - Displacements, Plane 5, Tensile Load Case 1.5

DEAC

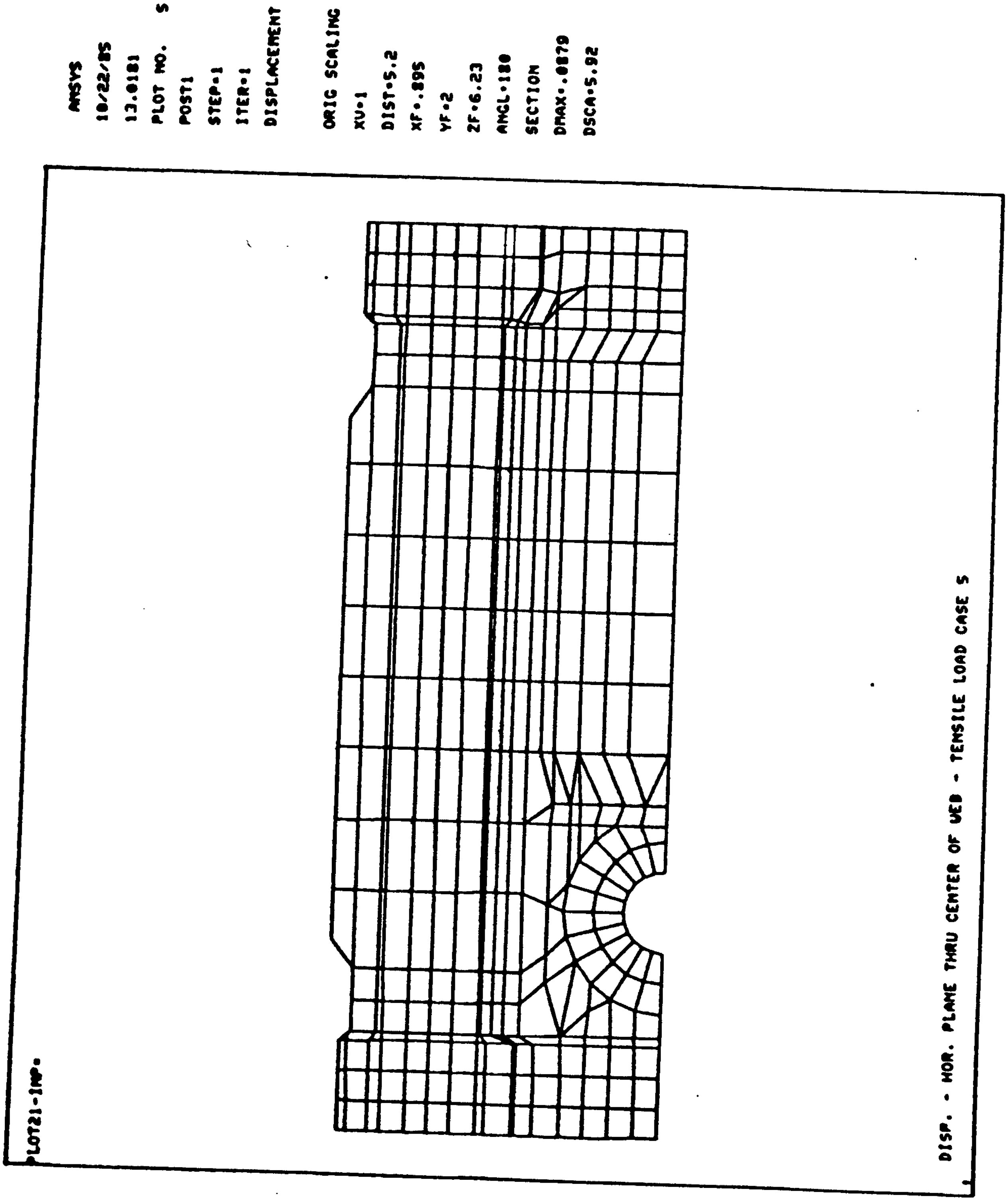


Figure 5-12 - Displacements, Plane 6, Tensile Load Case 1.5

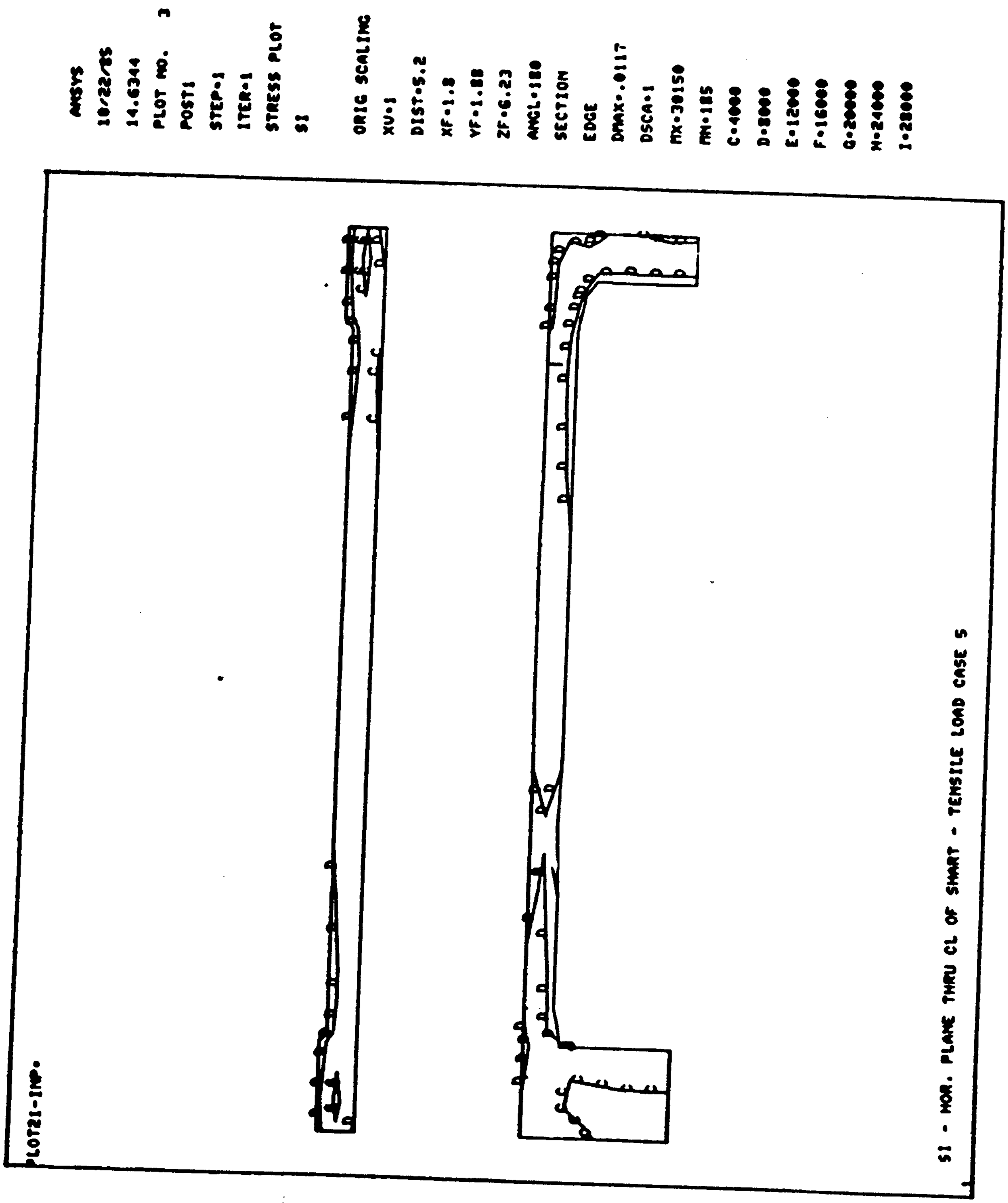


Figure 5-13 - Stress Intensity, Plane 1, Tensile Load Case 1.5

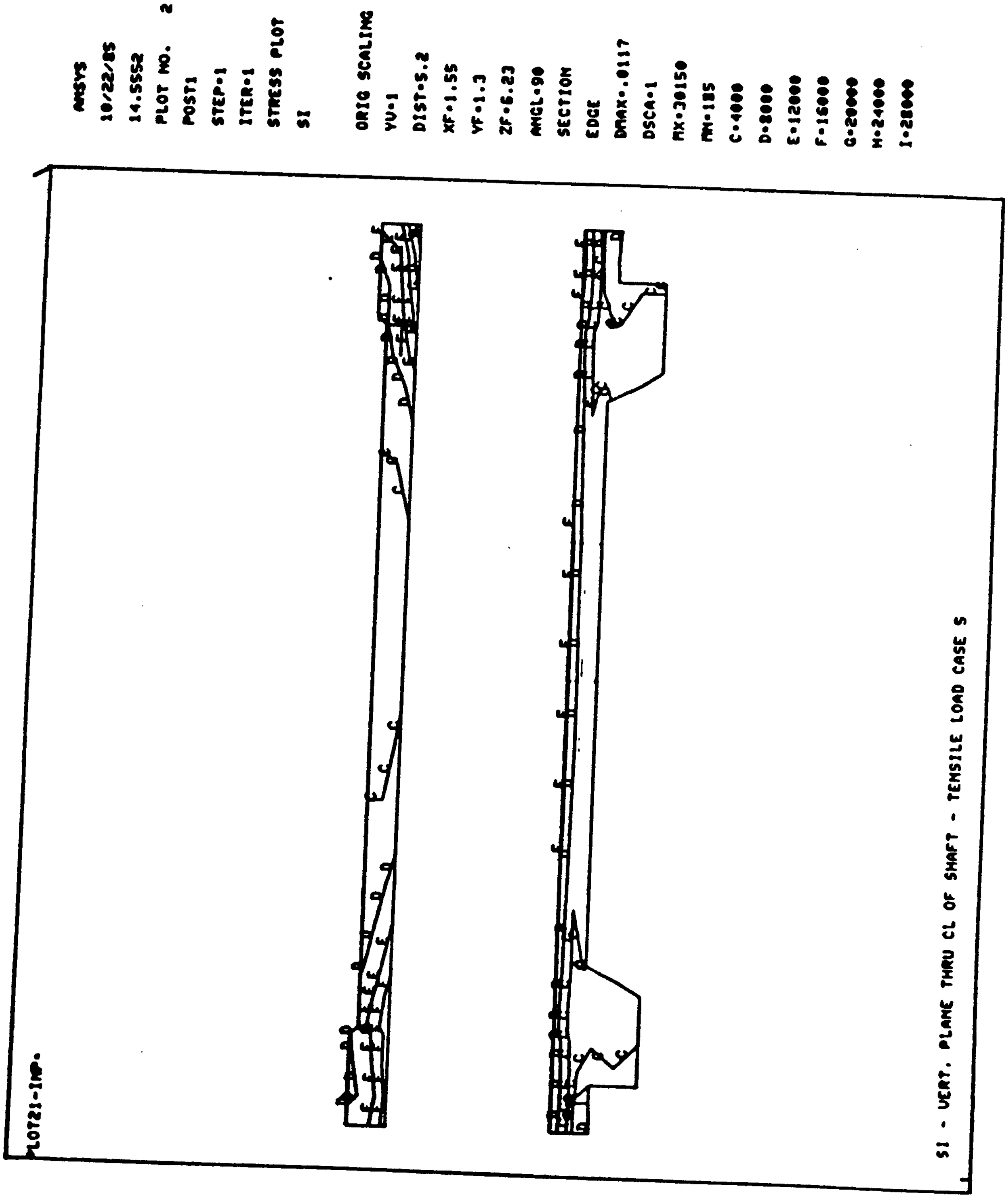


Figure 5-14 - Stress Intensity, Plane 2, Tensile Load Case 1.5

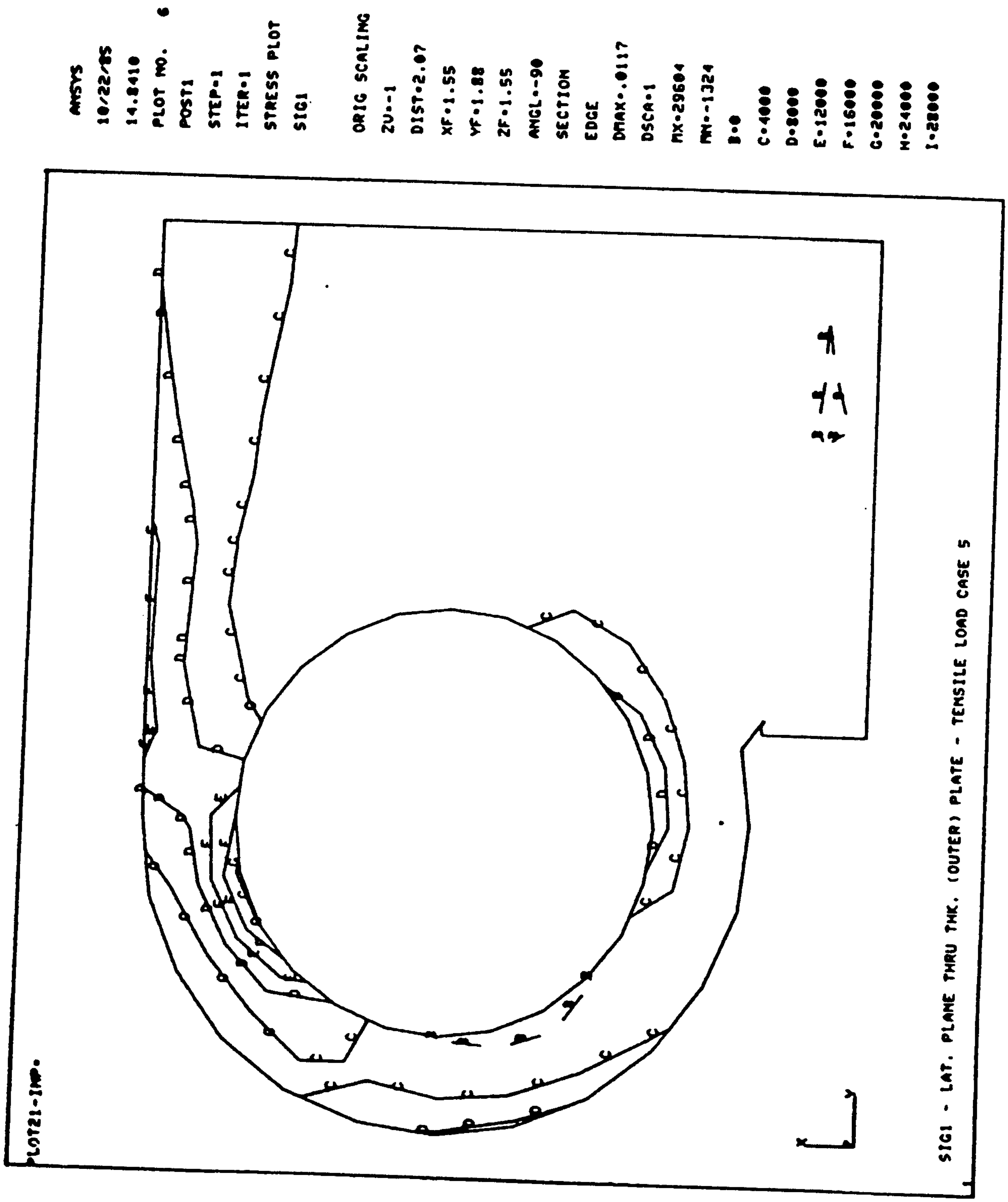


Figure 5-15 - SIG1 Principal Stress, Plane 3, Tensile Load Case 1.5

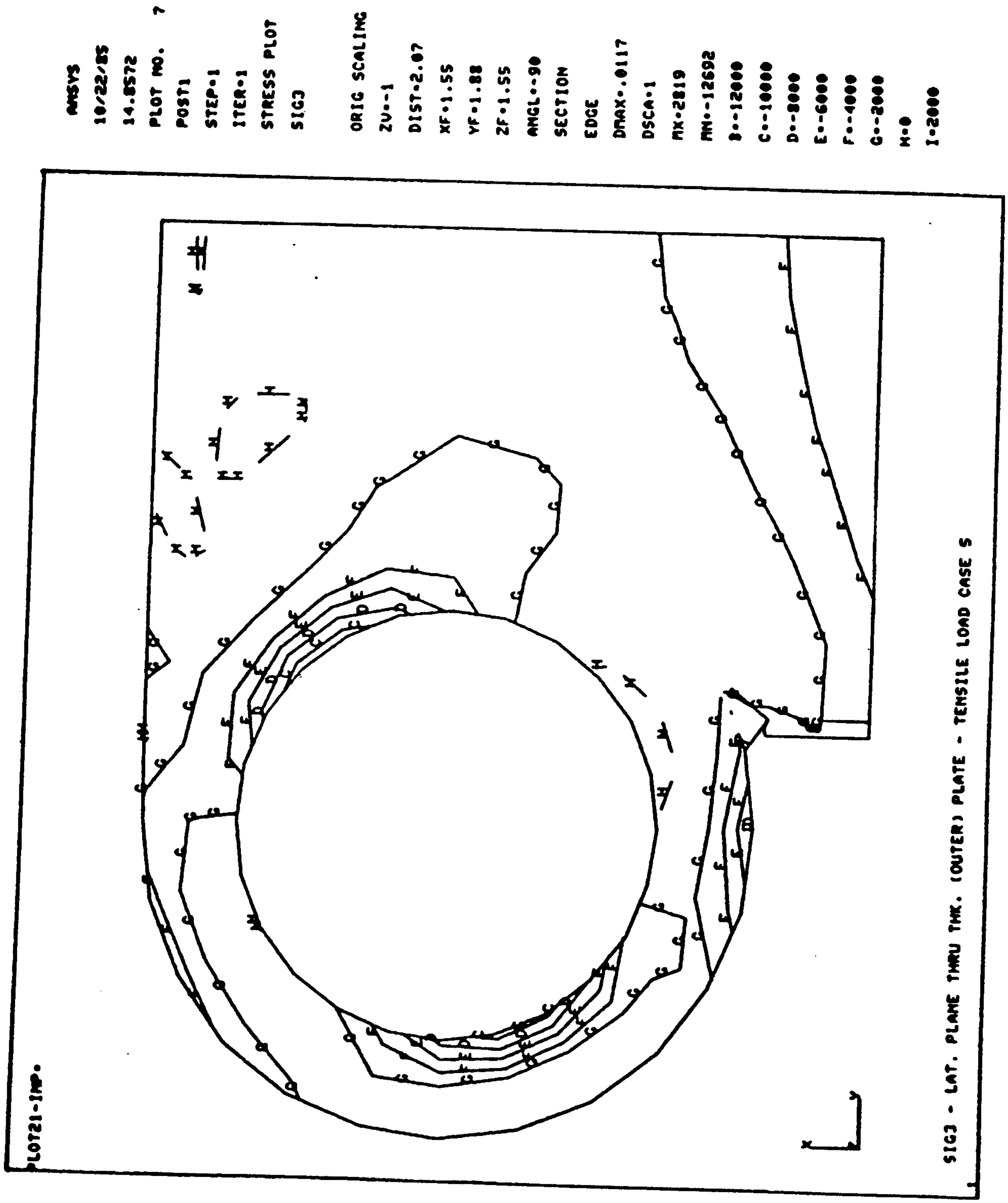


Figure 5-16 - SIG3 Principal Stress, Plane 3, Tensile Load Case 1.5

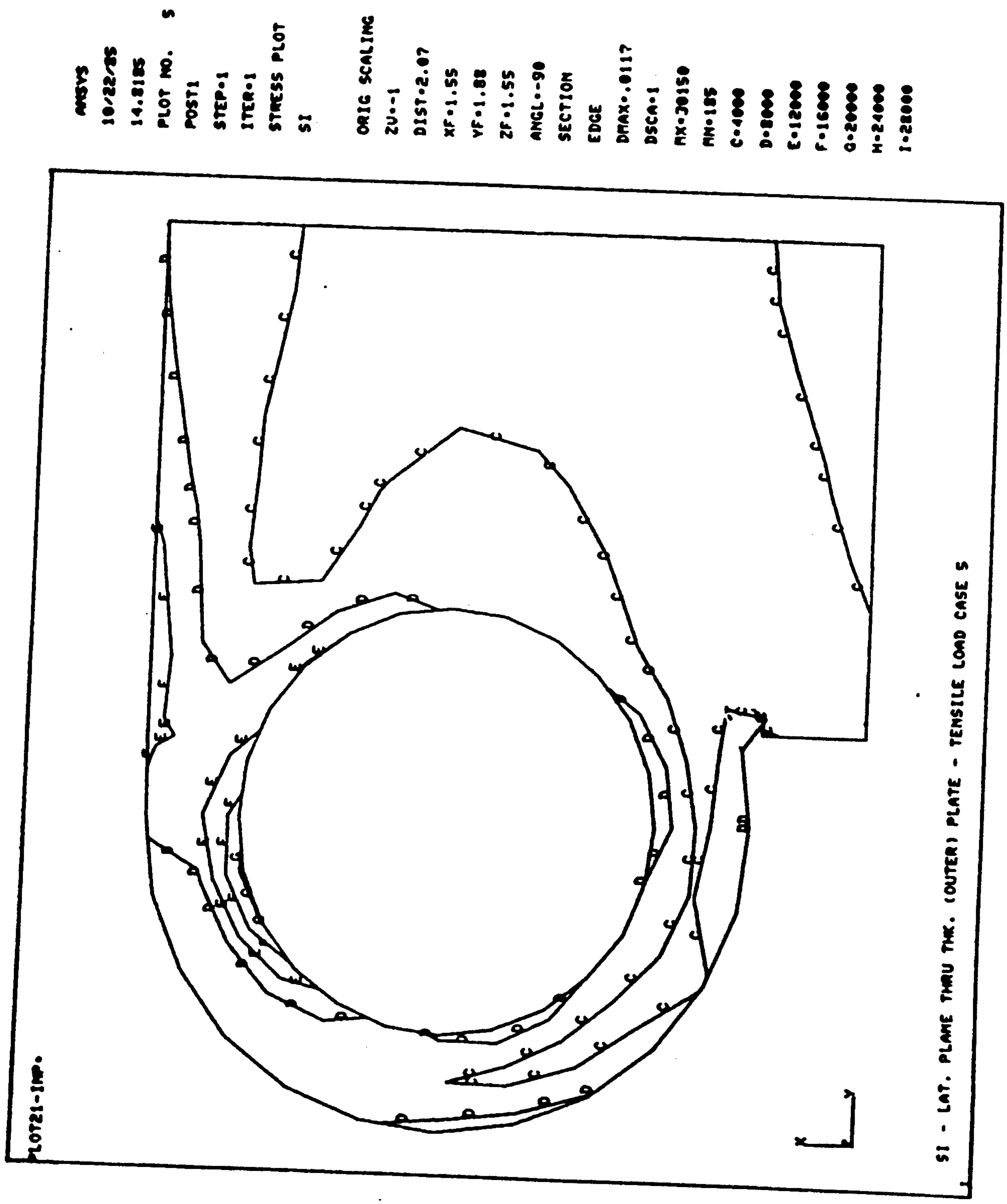


Figure 5-17 - Stress Intensity, Plane 3, Tensile Load Case 1.5

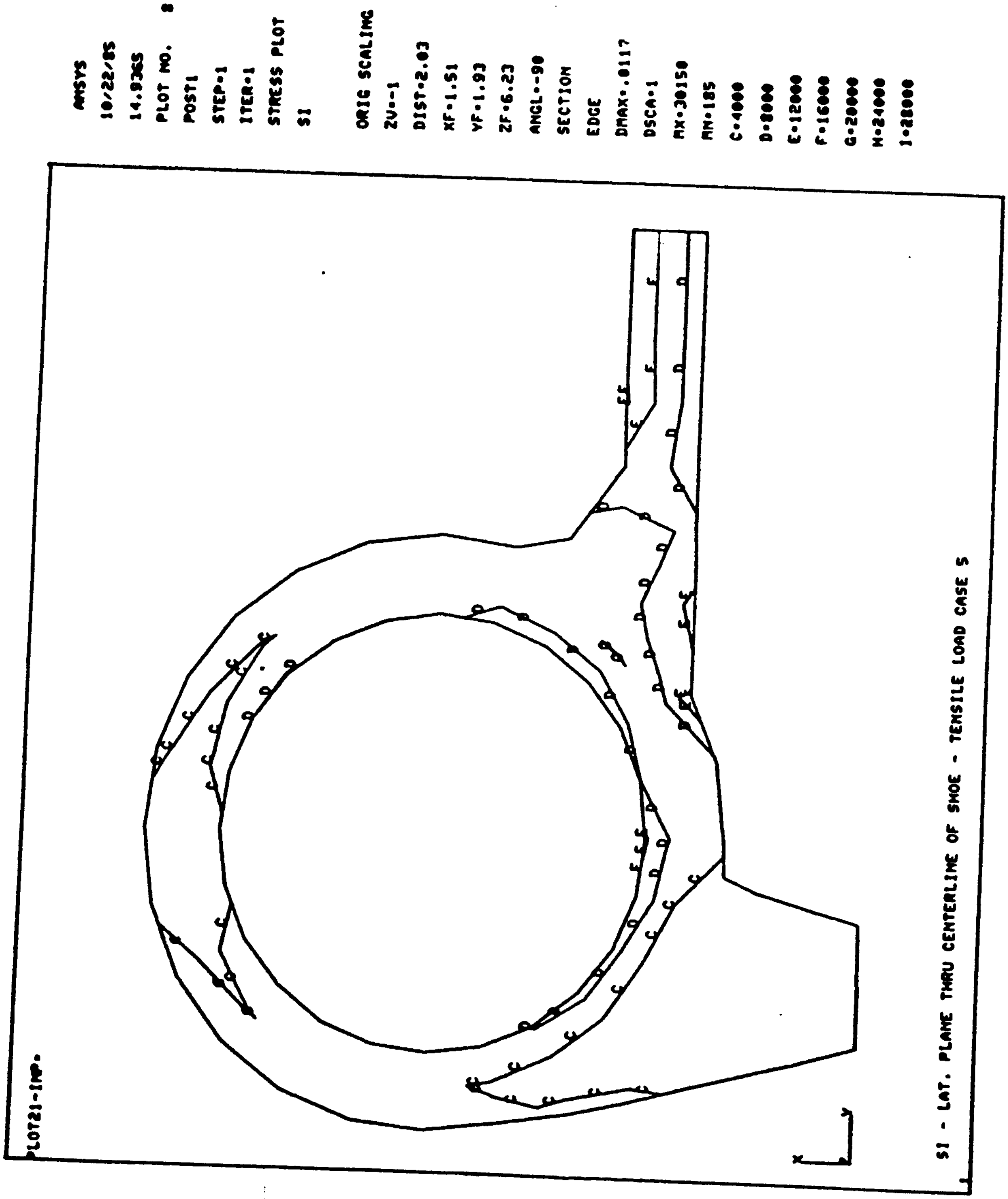


Figure 5-18 - Stress Intensity, Plane 4, Tensile Load Case 1.5

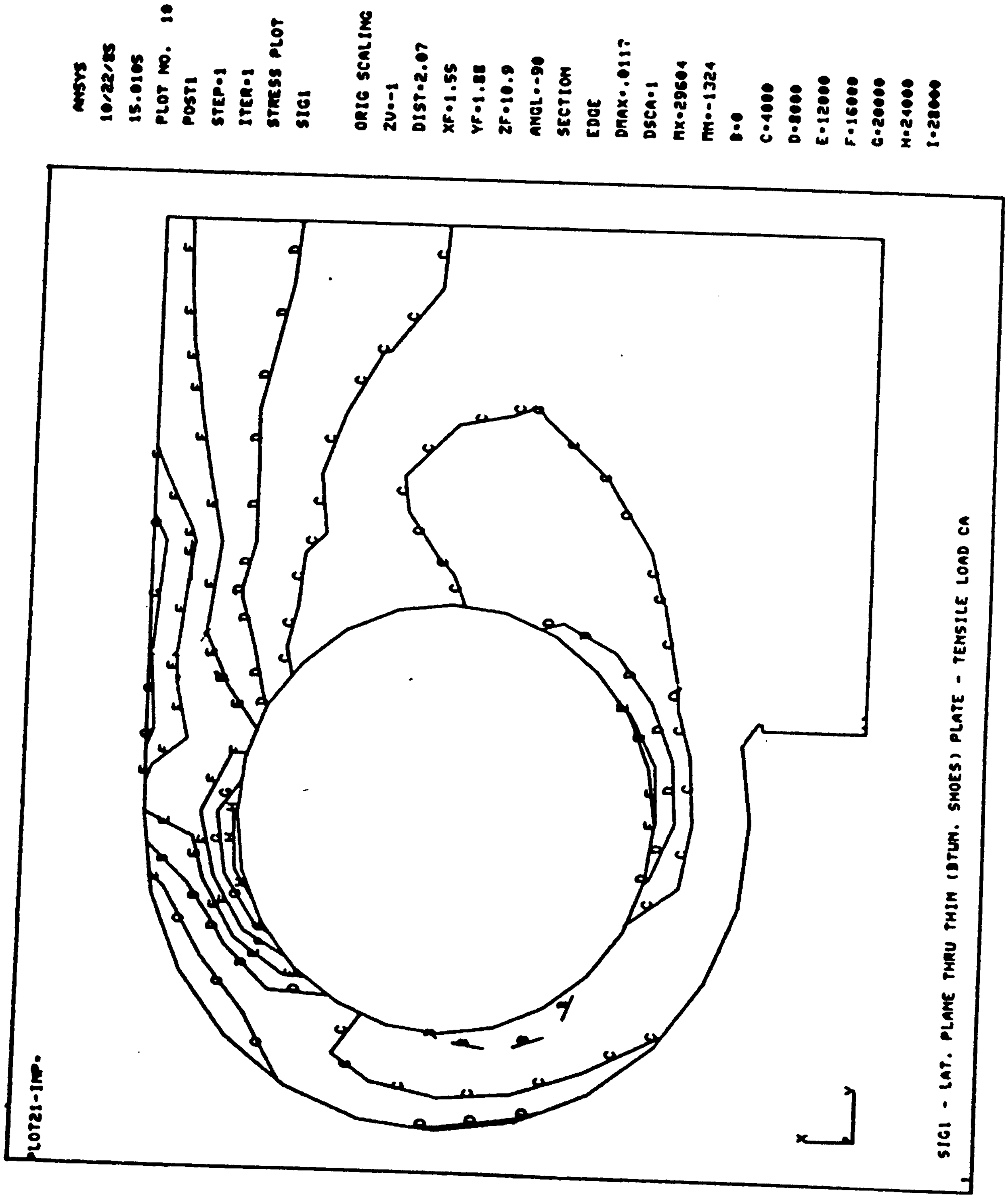


Figure 5-19 - SIG1 Principal Stress, Plane 5, Tensile Load Case 1.5

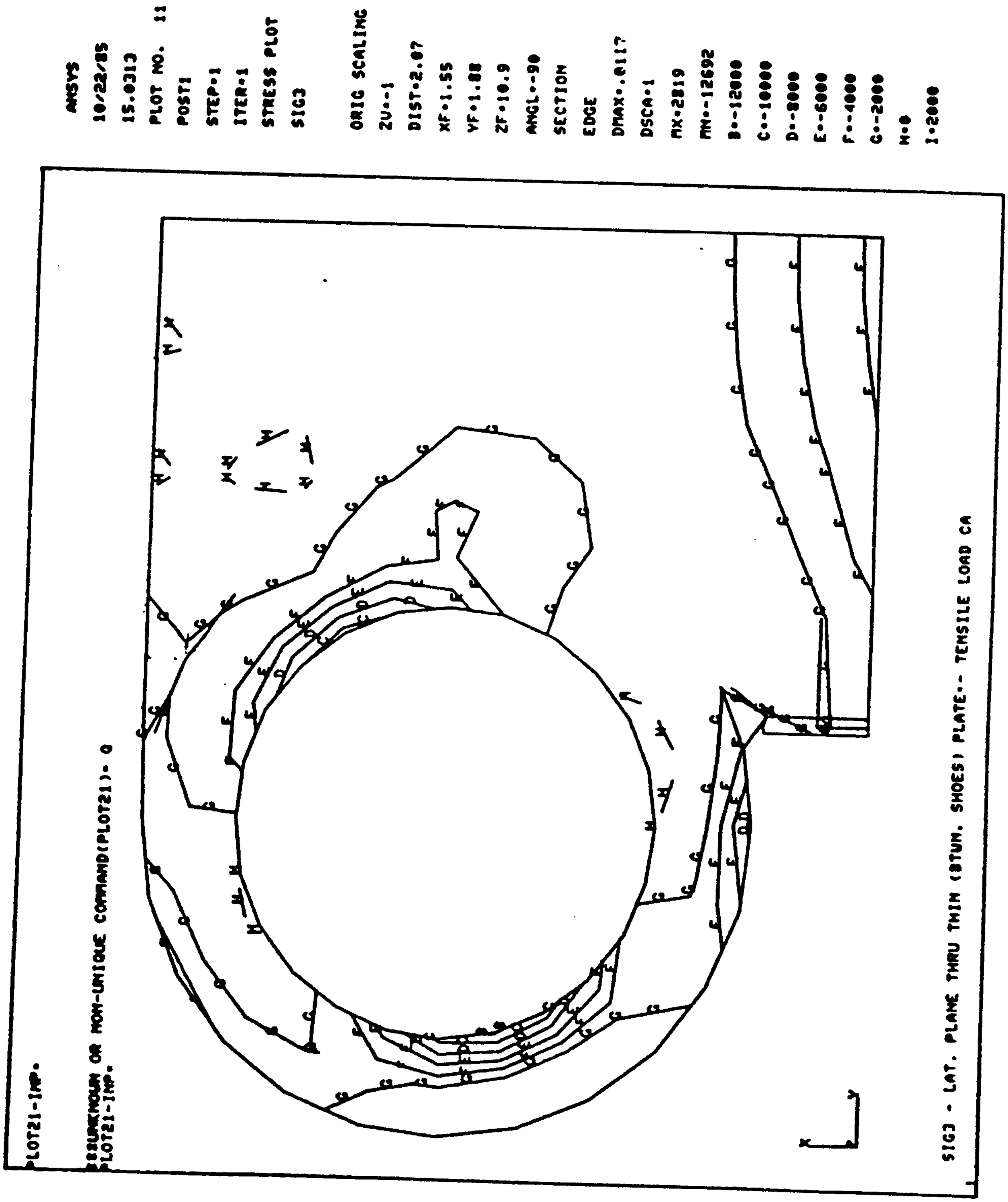


Figure 5-20 - SIG3 Principal Stress, Plane 5, Tensile Load Case 1.5

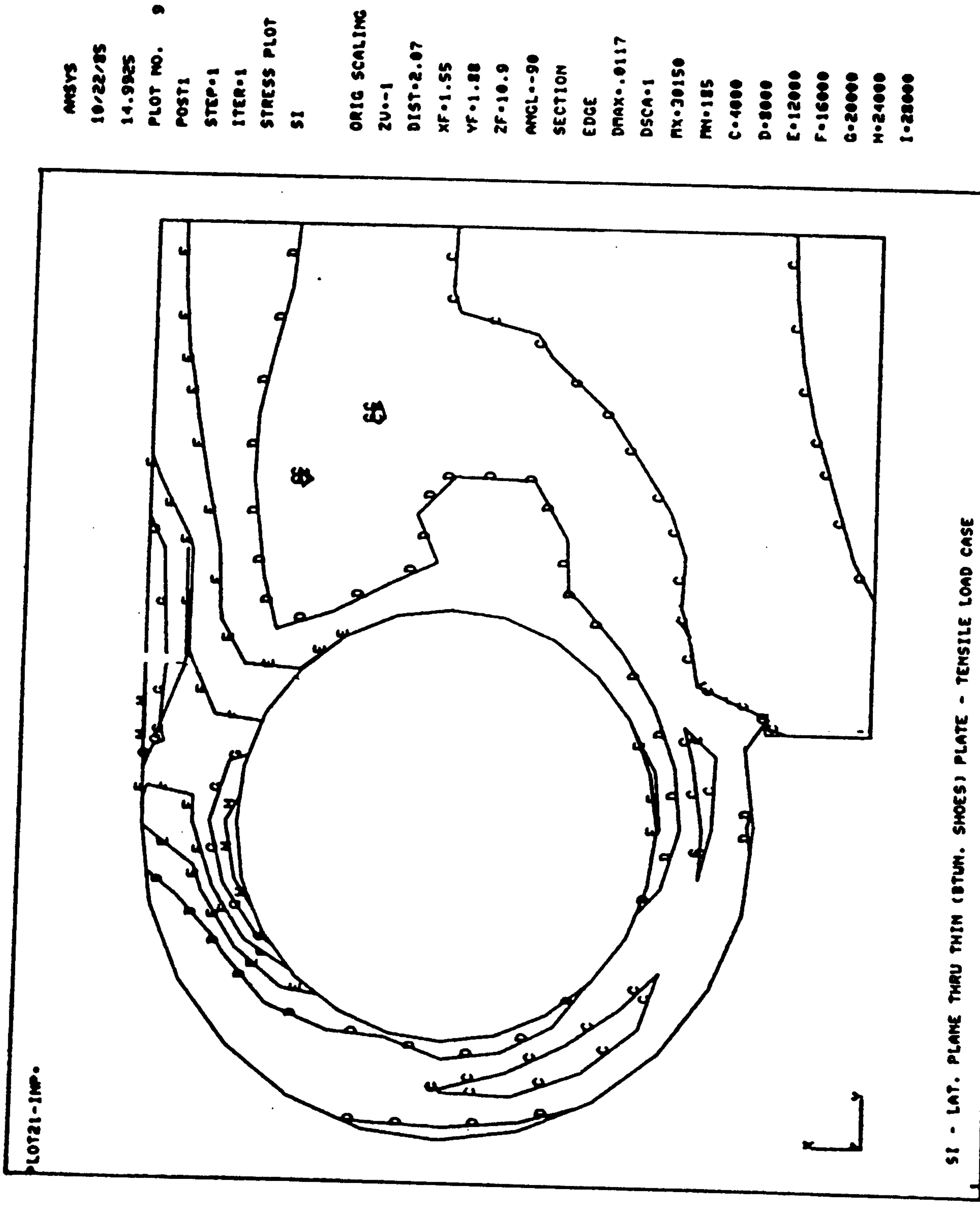


Figure 5-21 - Stress Intensity, Plane 5, Tensile Load Case 1.5

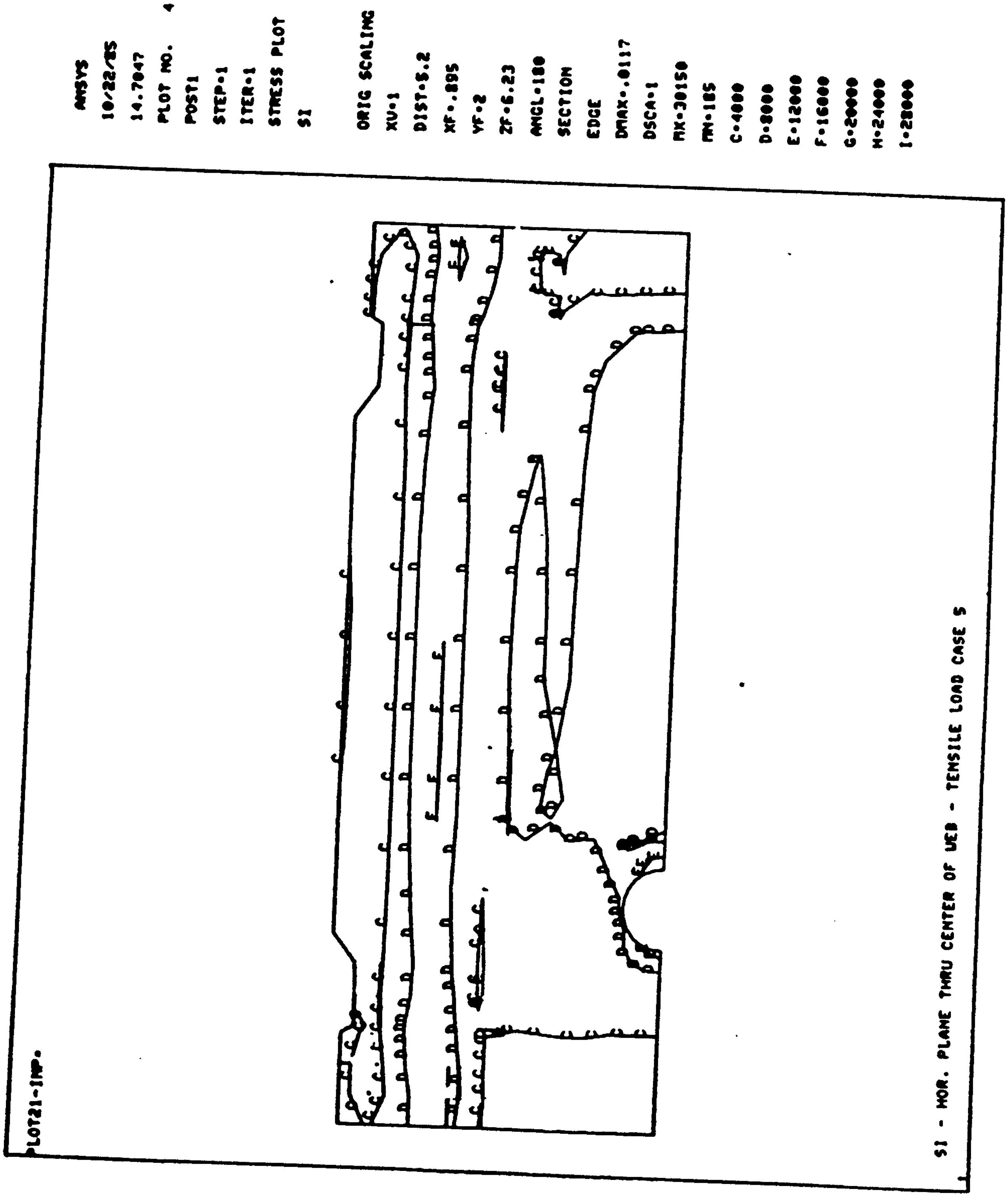


Figure 5-22 - Stress Intensity, Plane 6, Tensile Load Case 1.5

5.3 Out-of-Plane Load

The displacement and stress results for the out-of-plane loading (Case 2) are presented in this section. A free body diagram for this load case is illustrated in Figure 3-2. The load is applied at a 30° angle with the horizontal plane of the shoe. The same set of tables and plots that were presented in Section 5.2 for the pure tensile load case are presented here.

Tables 5-17 to 5-23 summarize the maximum stresses that were calculated for the out-of-plane load in the various element types. Figures 5-23 to 5-28 show displacement plots at the six cutting planes which are illsutrated in Figure 5-3. Stress contour plots for the same six planes are shown in Figures 5-29 to 5-38.

TABLE 5-17
Maximum Stress Summary
Type 1 - Steel Shaft
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 1 TO 1 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
274	4615.8953	-2680.8324	-96297.702	100913.60	97470.289
41	96230.051	2720.7605	-4619.1590	100849.21	97386.922
20	95986.090	2682.8524	-4610.5677	100596.66	97155.483
335	4606.0145	-2721.4867	-95973.909	100579.92	97123.704
2813	94634.719	6867.5491	-4636.8602	99271.579	94048.588
2801	4632.2227	-6905.0112	-94636.217	99268.439	94032.163
2800	4622.5381	-6859.7752	-94338.492	98961.031	93748.747
2812	94258.970	6897.9600	-4625.3317	98884.301	93655.852
275	-17167.834	-28763.181	-115544.96	98377.121	93122.463
42	115491.45	28784.446	17169.038	98322.414	93059.979
19	115233.89	28708.140	17118.601	98115.286	92864.503
336	-17126.912	-28733.779	-115230.85	98103.942	92846.235
221	4381.5230	-1011.8830	-91571.924	95953.447	93373.642
91	91431.748	1127.5092	-4379.5127	95811.261	93179.881
10	90734.753	1002.5500	-4358.9349	95093.688	92529.518

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
274	1	45	1	333	183	159	309	334	184	160	310
41	1	45	1	345	195	171	321	346	196	172	322
20	1	45	1	346	196	172	322	347	197	173	323
335	1	45	1	334	184	160	310	335	185	161	311
2813	1	45	1	3796	3646	3622	3772	3797	3647	3623	3773
2801	1	45	1	3784	3634	3610	3760	3785	3635	3611	3761
2800	1	45	1	3783	3633	3609	3759	3784	3634	3610	3760
2812	1	45	1	3795	3645	3621	3771	3796	3646	3622	3772
275	1	45	1	183	33	9	159	184	34	10	160
42	1	45	1	195	45	21	171	196	46	22	172
19	1	45	1	196	46	22	172	197	47	23	173
336	1	45	1	184	34	10	160	185	35	11	161
221	1	45	1	332	182	158	308	333	183	159	309
91	1	45	1	344	194	170	320	345	195	171	321
10	1	45	1	347	197	173	323	348	198	174	324

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
184	15733.365	-12141.243	-152011.11	167744.47	155793.88
196	151964.15	12167.803	-15730.082	167694.24	155735.09
3784	14301.848	-18600.179	-152114.80	166416.65	152731.12
3796	152033.42	18631.404	-14296.823	166330.24	152636.62
183	15237.262	-11512.837	-147425.31	162662.58	151184.37
195	147340.72	11578.625	-15233.476	162574.20	151072.78
197	146647.65	11525.842	-15167.536	161815.18	150366.52
185	15169.490	-11548.121	-146642.74	161812.24	150354.27
3785	13858.187	-17840.582	-147520.78	161378.97	148183.03
3797	147493.50	17824.561	-13854.612	161348.11	148159.45
3783	13780.979	-17761.048	-146679.81	160460.79	147333.29
3795	146567.53	17828.672	-13775.768	160343.30	147195.31
182	13718.126	-9667.7760	-133239.07	146957.19	136901.09
194	133123.49	9769.6926	-13714.171	146837.66	136744.16
3798	133290.31	15431.186	-12481.228	145771.54	134117.39

TABLE 5-18
Maximum Stress Summary
Type 2 - Rubber Bushing
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 2 TO 2 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
86	1218.2145	-3.2244717	-318.31885	1536.5334	1405.7263
169	1362.7547	-3.7884364	-173.53079	1536.2855	1458.8396
40	1042.6249	-2.3942384	-492.55219	1535.1771	1358.1400
223	1465.5919	-4.0294785	-69.068134	1534.6600	1503.1963
277	1518.9196	-3.1547860	-13.665133	1532.5847	1527.3566
35	848.46097	-1.3521927	-683.23967	1531.7006	1329.1463
337	1518.6367	-2.9523359	-9.8934640	1528.5302	1525.0715
31	649.20451	-0.15311891	-875.99280	1525.1973	1325.7050
400	1464.6788	-4.0897309	-57.543924	1522.2228	1496.2120
475	1360.8359	-3.6829428	-156.04670	1516.8826	1446.7307
27	458.54167	1.1590437	-1056.8010	1515.3427	1346.2433
524	1214.3464	-3.0685211	-296.59045	1510.9368	1387.6571
509	1035.7738	-2.2841568	-467.82071	1503.5945	1333.2451
24	289.40675	2.4983431	-1213.5428	1502.9496	1382.0148
433	838.89732	-1.2468135	-656.29311	1495.1904	1298.1761

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
86	2	45	2	654	504	480	630	655	505	481	631
169	2	45	2	655	505	481	631	656	506	482	632
40	2	45	2	653	503	479	629	654	504	480	630
223	2	45	2	656	506	482	632	657	507	483	633
277	2	45	2	657	507	483	633	658	508	484	634
35	2	45	2	652	502	478	628	653	503	479	629
337	2	45	2	658	508	484	634	659	509	485	635
31	2	45	2	651	501	477	627	652	502	478	628
400	2	45	2	659	509	485	635	660	510	486	636
475	2	45	2	660	510	486	636	661	511	487	637
27	2	45	2	650	500	476	626	651	501	477	627
524	2	45	2	661	511	487	637	662	512	488	638
509	2	45	2	662	512	488	638	663	513	489	639
24	2	45	2	673	523	499	649	650	500	476	626
433	2	45	2	663	513	489	639	664	514	490	640

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
483	1717.1700	-7.6636285	-67.458473	1784.6285	1755.9679
484	1750.4883	-11.124163	-32.821266	1783.3096	1772.5638
485	1717.4216	-7.9304676	-58.891924	1776.3135	1751.7534
482	1621.0073	-7.5421120	-151.40077	1772.4081	1706.5936
486	1620.9659	-7.3033460	-135.63020	1756.5960	1697.4913
481	1471.5666	-6.4980611	-284.66191	1756.2285	1637.2797
480	1282.1424	-4.7515346	-459.10820	1741.2506	1566.6105
487	1469.6366	-6.2110636	-262.67529	1732.3119	1621.6275
479	1067.3623	-2.6032371	-662.61480	1729.9771	1514.0018
478	842.29986	-0.25688549	-880.03575	1722.3356	1493.3700
497	60.031191	7.7759628	-1658.7586	1718.7898	1693.6506
498	135.37839	7.3951682	-1582.6662	1718.0446	1659.1464
477	622.66409	2.1110496	-1094.9039	1717.5680	1508.3223
499	258.31872	6.2043050	-1457.7639	1716.0826	1607.1292
633	1649.5389	-6.8910587	-66.361951	1715.9008	1687.4279

TABLE 5-19
Maximum Stress Summary
Type 3 - Shoe Binocular
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 3 TO 3 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1514	13252.178	2288.2357	391.97263	12860.206	12024.740
1991	6687.6115	39.045640	-6154.2696	12841.881	11123.724
1544	12961.147	1517.6307	264.89349	12696.253	12118.545
658	5543.5383	-580.43831	-6980.6534	12524.192	10847.148
1511	12738.746	2566.9995	321.17322	12417.573	11460.896
659	5269.9780	168.20061	-7028.9462	12298.924	10702.584
1841	9070.6939	752.24362	-3090.7651	12161.459	10767.228
1609	11815.156	871.12248	-235.89749	12051.054	11537.445
1510	12324.175	2594.7279	390.35758	11933.817	10998.577
1721	9959.9714	547.93562	-1681.5530	11641.524	10702.386
657	5136.0857	-502.90161	-5756.7971	10892.883	9435.4780
1375	10779.714	1876.7538	-58.697477	10838.412	10011.989
636	376.93346	-3242.2496	-10184.705	10561.638	9296.3535
755	255.33361	-3756.6445	-10166.094	10421.427	9104.4811
1515	1045.4047	-4774.8347	-9200.9995	10246.404	8900.9808

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1514	3	45	3	2528	2378	2354	2504	2529	2379	2355	2505
1991	3	45	3	3278	3128	3104	3254	3279	3129	3105	3255
1544	3	45	3	2678	2528	2504	2654	2679	2529	2505	2655
658	3	45	3	1177	1027	1003	1153	1178	1028	1004	1154
1511	3	45	3	2378	2228	2204	2354	2379	2229	2205	2355
659	3	45	3	1178	1028	1004	1154	1179	1029	1005	1155
1841	3	45	3	3128	2978	2954	3104	3129	2979	2955	3105
1609	3	45	3	2828	2678	2654	2804	2829	2679	2655	2805
1510	3	45	3	2228	2078	2054	2204	2229	2079	2055	2205
1721	3	45	3	2978	2828	2804	2954	2979	2829	2805	2955
657	3	45	3	1176	1026	1002	1152	1177	1027	1003	1153
1376	3	45	3	2078	1928	1904	2054	2079	1929	1905	2055
636	3	45	3	1155	1005	957	1107	1156	1006	958	1108
765	3	45	3	1305	1155	1107	1257	1306	1156	1108	1258
1515	3	45	3	2504	2354	2306	2456	2505	2355	2307	2457

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
2307	2522.0750	-6710.4867	-17413.560	19935.635	17283.573
2457	2741.0630	-7137.9177	-16987.672	19728.735	17092.948
2157	2422.0942	-6543.2952	-17201.828	19623.923	17018.598
2007	2299.6484	-6189.5667	-16648.739	18948.387	16442.414
2607	2877.1583	-7635.7651	-15974.661	18851.820	16374.573
2757	2884.1326	-7491.4637	-15089.682	17973.815	15645.512
2907	2901.5928	-6699.0273	-14462.543	17364.136	15082.132
1706	4337.4787	-5157.3232	-12494.727	16832.205	14654.654
1857	1384.2417	-5937.4461	-15415.233	16799.474	14589.321
3057	3377.8724	-5064.3545	-13215.272	16593.145	14384.970
1628	15064.938	2420.7917	-1489.8587	16554.797	15127.855
1407	2263.5125	-5505.1124	-13992.173	16255.685	14088.870
1557	1456.6494	-6264.6986	-14588.612	16045.262	13899.007
1703	16314.333	3660.6593	296.31517	16018.018	14630.545
2908	464.53519	-6602.9869	-15445.545	15910.080	13808.276

TABLE 5-20
Maximum Stress Summary
Type 4 - Shoe End Plates
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 4 TO 4 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
2636	15076.190	595.98892	-258.89035	15335.080	14926.013
2632	14108.701	428.67080	-256.16264	14364.863	14034.983
2141	7863.8084	585.92075	-5893.3402	13757.149	11920.730
2525	11774.104	-220.19775	-1295.4348	13069.539	12566.469
2199	4245.9898	-413.89842	-8677.2076	12923.197	11335.913
2629	12577.927	218.36296	-272.76061	12850.688	12612.300
2160	9024.3045	858.14746	-3818.9652	12843.270	11258.576
2540	12355.778	1806.9329	-485.38743	12841.166	11862.302
569	12026.607	151.70526	-750.87437	12777.482	12350.951
429	7544.7893	1055.0033	-5133.0204	12677.810	10980.342
2187	5482.3917	-580.87435	-7085.1751	12567.567	10886.066
219	7388.2256	-169.79216	-5084.2903	12472.516	10882.086
2403	5866.8254	-306.36892	-6572.0793	12438.905	10772.507
432	6979.9064	1583.6890	-5423.9109	12403.817	10772.193
2383	6730.9104	-247.47468	-5522.4609	12253.371	10645.855

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
2636	4	45	3	4824	4837	4838	4825	4941	4954	4955	4942
2632	4	45	3	4811	4824	4825	4812	4928	4941	4942	4929
2141	4	45	3	3278	4662	4663	3279	3428	4779	4780	3429
2525	4	45	3	4649	4655	4656	4650	4766	4772	4773	4767
2199	4	45	3	4704	4717	4718	4705	4821	4834	4835	4822
2629	4	45	3	4798	4811	4812	4799	4915	4928	4929	4916
2160	4	45	3	4662	4675	4676	4663	4779	4792	4793	4780
2540	4	45	3	4823	4836	4837	4824	4940	4953	4954	4941
569	4	45	3	4149	4155	4156	4150	4266	4272	4273	4267
429	4	45	3	4295	4412	4296	4296	4308	4425	4309	4309
2187	4	45	3	4691	4704	4705	4692	4808	4821	4822	4809
219	4	45	3	877	4278	4279	878	1027	4395	4396	1028
2403	4	45	3	4705	4718	4719	4706	4822	4835	4836	4823
432	4	45	3	4308	4425	4309	4309	4321	4438	4322	4322
2383	4	45	3	4692	4705	4706	4693	4809	4822	4823	4810

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
4718	1435.0949	-4209.7251	-20151.315	21586.410	19425.474
4705	3066.3347	-3723.7248	-18429.291	21495.625	19077.672
4692	6886.7682	-2258.9721	-13482.061	20368.829	17704.852
4717	3627.5398	-1872.6046	-15881.876	19509.416	17426.714
4650	18481.812	499.02631	-916.15187	19397.964	18732.189
1028	11265.077	-420.06881	-7678.2157	18943.292	16577.540
4955	18567.815	790.31294	-233.30728	18801.123	18310.784
4267	18928.312	1207.5518	153.82718	18774.485	18272.050
4679	10104.631	-883.27234	-8566.2756	18670.906	16276.167
4704	4333.2215	-1606.7418	-14325.334	18658.555	16535.995
4259	19045.889	1670.2132	885.43280	18160.456	17789.532
4942	17893.811	668.04334	-216.19431	18110.006	17684.481
3278	7157.2677	-1572.6711	-10926.670	18083.938	15822.385
4642	18671.220	1740.7934	847.85541	17823.365	17394.162
4260	19122.406	1704.3462	1304.9010	17817.505	17621.179

TABLE 5-21
Maximum Stress Summary
Type 5 - Shoe Rib and Wall
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 5 TO 5 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1048	10662.556	.2509.5067	-4216.0611	14878.617	12905.013
1679	9334.5228	1995.7399	-4040.8169	13375.340	11601.669
2175	12054.591	1515.4654	882.83056	11171.760	10869.260
548	11396.047	1368.5887	593.88388	10802.164	10436.399
2137	9405.8134	1079.0783	-1222.3646	10628.178	9684.7645
496	7791.6739	461.50786	-1973.3858	9765.0597	8803.8751
2003	5717.1250	531.42874	-2001.3139	7718.4389	6814.7095
495	5119.7311	171.75653	-2265.1930	7384.9241	6517.6023
540	6615.7281	571.49824	-615.03268	7230.7608	6716.5643
539	5985.9491	-137.54313	-1200.9689	7186.9180	6718.6242
494	4807.4783	312.67707	-2263.4454	7070.9237	6198.2904
2136	4709.6410	275.28042	-2183.6518	6893.2929	6050.9251
541	6313.2370	1108.0019	-333.18254	6646.4195	6055.8392
2024	6409.9034	893.76067	-38.883022	6448.7865	6036.7417
2332	5931.3743	471.87511	-498.13031	6429.5046	6003.5644

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1048	5	45	3	1485	1484	5218	5218	5065	5065	5065	5065
1679	5	45	3	2685	2684	5242	5242	5085	5085	5085	5085
2175	5	45	3	5274	4643	4760	4760	5174	4642	4759	4759
548	5	45	3	5254	4260	4143	4143	5154	4259	4142	4142
2137	5	45	3	5174	4642	4759	4759	3282	4641	4758	4758
496	5	45	3	5154	4259	4142	4142	882	4258	4141	4141
2003	5	45	3	5177	5174	5173	5173	3133	3282	3283	3283
495	5	45	3	4142	5151	5153	5154	4141	733	883	882
540	5	45	3	4025	5151	4142	4142	4024	733	4141	4141
539	5	45	3	4025	5150	5151	5151	4024	734	733	733
494	5	45	3	5157	5154	5153	5153	1033	882	883	883
2136	5	45	3	4759	5171	5173	5174	4758	3433	3283	3282
541	5	45	3	5150	5152	5153	5151	734	884	883	733
2024	5	45	3	5277	5274	5273	5273	5177	5174	5173	5173
2332	5	45	3	4876	5171	4759	4759	4875	3433	4758	4758

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
4259	15018.702	2638.9299	-364.42270	15383.124	14123.639
4642	13467.240	1793.7627	-1346.0736	14813.314	13525.990
4641	8850.2244	-403.39538	-5663.6345	14513.859	12726.973
4258	8661.8035	-297.56927	-5319.5357	13981.339	12267.199
4643	11018.751	54.610889	-1616.0534	12634.805	11887.846
4260	10789.451	24.846691	-1470.8738	12260.325	11585.108
3282	4093.7498	-1391.6695	-6222.4036	10316.153	8945.5925
734	11640.573	2174.2393	1451.5546	10189.018	9852.0838
882	3439.5335	-1517.4311	-6405.2506	9844.7841	8530.7755
5174	6813.1421	402.82771	-2304.2158	9117.3579	8233.8582
4141	2149.4393	-3463.6397	-6938.8893	9088.3287	8272.7058
1484	4646.6811	19.202616	-4308.3013	8954.9824	7843.0377
5154	6287.5430	247.51567	-2513.1122	8800.6552	7936.4287
5274	7031.0234	86.673076	-1637.3655	8668.3889	8022.3280
2684	4327.9840	-175.06964	-4333.4958	8661.4798	7586.7828

TABLE 5-22
Maximum Stress Summary
Type 6 - Shoe Web
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 6 TO 6 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
692	9337.4465	-5441.8741	-30757.249	40094.695	35120.372
1887	16980.453	8499.0591	-18123.885	35104.338	31725.618
695	9500.2967	-4175.8041	-24885.108	34385.405	29985.555
1464	22964.632	530.51986	-8074.9670	31039.599	27756.085
689	10385.500	-4884.5697	-18077.875	28463.375	24671.867
1875	13613.873	8049.2711	-13444.238	27058.111	24749.516
1460	7745.2195	-5335.5806	-16459.611	24204.830	20984.818
1754	10465.323	1192.4625	-13726.543	24191.866	21140.117
2041	5020.8200	3131.0815	-16572.332	21593.152	20713.037
1463	2847.7309	-5730.0085	-18413.742	21261.473	18527.074
1827	6845.6399	3139.1619	-12996.326	19841.966	18272.871
1457	12371.168	777.98660	-6062.4221	18433.590	16139.862
1707	10732.555	422.90573	-7056.4023	17788.957	15470.551
817	3006.8911	-3673.8248	-14206.196	17213.087	15030.855
936	7555.5379	-1378.8775	-9554.3232	17109.861	14822.433

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
692	6	45	3	4437	6441	6641	4436	4424	6442	6642	4423
1887	6	45	3	6109	6115	6114	6108	6309	6315	6314	6308
695	6	45	3	4450	6440	6640	4449	4437	6441	6641	4436
1464	6	45	3	6436	6457	6437	6437	6636	6657	6637	6637
689	6	45	3	4424	6442	6642	4423	4411	6443	6643	4410
1875	6	45	3	6108	6114	6113	6107	6308	6314	6313	6307
1460	6	45	3	6236	6257	6237	6237	6436	6457	6437	6437
1754	6	45	3	6102	6108	6107	6101	6302	6308	6307	6301
2041	6	45	3	6114	6115	4717	4704	6314	6315	4716	4703
1463	6	45	3	6237	6437	6259	6259	6257	6457	6258	6258
1827	6	45	3	6103	6109	6108	6102	6303	6309	6308	6302
1457	6	45	3	6036	6057	6037	6037	6236	6257	6237	6237
1707	6	45	3	6096	6102	6101	6095	6296	6302	6301	6295
817	6	45	3	6442	6429	6445	6443	6642	6629	6645	6643
936	6	45	3	6229	6230	6245	6245	6429	6430	6445	6445

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
6108	24311.270	16564.746	-33590.010	57901.280	54473.510
4423	38193.023	6551.7101	-13515.157	51708.180	45173.553
6109	29148.776	23003.003	-19663.034	48811.810	46089.445
4436	43337.467	11479.486	-3466.1889	46803.656	41504.681
6642	13337.352	-5801.7026	-32342.977	45680.329	40147.122
6102	30191.941	15914.588	-13599.022	43790.964	38996.105
4449	39008.882	12144.028	-1804.6723	40813.554	35930.717
6114	19844.162	14169.383	-20188.618	40032.780	37584.843
6096	26313.481	7302.3059	-10487.748	36801.229	32054.684
6115	23125.762	20937.211	-13564.047	36689.810	35646.211
6303	19499.853	-10368.209	-16682.582	36182.435	33474.948
6641	14775.873	-4415.9639	-21405.168	36181.042	31498.670
6090	24631.656	3629.0943	-9243.7720	33875.428	29618.092
4704	9999.0288	2956.0584	-23766.648	33765.677	30886.280
4717	9486.0838	7387.6456	-24093.172	33579.256	32580.760

TABLE 5-23
Maximum Stress Summary
Type 7 - Shoe Fillets
Out-of-Plane Load, Case 2

ERSE FOR LABEL= TYPE FROM 7 TO 7 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1888	17130.572	-7912.9835	-24497.912	41628.485	36298.556
1876	19312.860	-6447.8509	-16476.794	35789.655	31977.283
1546	23194.136	5614.9998	1196.9440	21997.192	20154.673
1611	22597.042	4047.9359	935.88662	21661.156	20284.968
1723	20019.536	1730.5850	-586.48573	20606.022	19550.738
1518	21915.646	5994.8875	1558.8012	20356.845	18541.178
1858	17567.761	-913.22802	-1985.2661	19553.027	19039.657
2042	28432.030	9441.5575	9088.2593	19343.771	19169.564
1517	20764.879	5614.0037	1548.9947	19215.884	17540.289
2032	24782.693	7672.6737	5636.2354	19146.458	18213.823
1516	19707.910	5487.3319	1681.2504	18026.660	16457.089
1843	14750.942	-1179.1753	-3187.2700	17938.212	17023.227
1395	19792.720	4838.3034	2061.7377	17730.983	16518.651
2010	18886.709	3370.4185	1179.7506	17706.958	16719.609
1394	19346.487	5013.2951	1849.4605	17497.027	16149.245

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1888	7	45	3	6308	7018	6314	6314	6309	7019	6315	6315
1876	7	45	3	6307	7017	6313	6313	6308	7018	6314	6314
1546	7	45	3	6288	6287	7005	7005	6294	6293	7006	7006
1611	7	45	3	6294	6293	7006	7006	6300	6299	7007	7007
1723	7	45	3	6300	6299	7007	7007	6306	6305	7008	7008
1518	7	45	3	6282	6281	7004	7004	6288	6287	7005	7005
1858	7	45	3	6306	7016	6312	6312	6307	7017	6313	6313
2042	7	45	3	6314	4703	4702	7018	6315	4716	4715	7019
1517	7	45	3	6276	6275	7003	7003	6282	6281	7004	7004
2032	7	45	3	6313	4690	4689	7017	6314	4703	4702	7018
1516	7	45	3	6270	6269	7002	7002	6276	6275	7003	7003
1843	7	45	3	6306	6305	7008	7008	7016	6311	7009	7009
1395	7	45	3	6263	6264	7001	7001	6254	6254	6254	6254
2010	7	45	3	6312	4677	4676	7016	6313	4690	4689	7017
1394	7	45	3	6264	6263	7001	7001	6270	6269	7002	7002

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
6308	24627.144	-10144.230	-37759.034	62386.177	54150.479
6307	26626.664	772.83906	-13100.479	39727.143	35364.497
7018	25132.515	-1221.1286	-13769.149	38901.664	34741.879
6314	24580.536	2650.1175	-11874.426	36454.962	32109.661
6309	12870.683	-12316.406	-21987.189	34857.872	31168.772
7019	23143.770	-3054.6141	-9543.1330	32686.903	30129.247
6315	22877.491	1469.3172	-7292.1337	30169.624	27348.379
6306	20033.257	133.41964	-6749.9461	26783.203	24213.443
7017	18747.771	2095.1592	-6326.9560	25074.727	22618.821
4715	27152.479	5892.6043	3037.3451	24115.134	22821.858
4702	27739.808	7752.0684	4354.2807	23385.527	21920.584
6294	23494.812	4558.8386	145.96247	23348.850	21488.696
4689	20779.908	1120.6431	-2503.7432	23283.652	21701.910
6300	21155.474	2174.5798	-478.40795	21633.882	20456.216
6288	22447.094	5885.6662	1409.7882	21037.306	19197.127

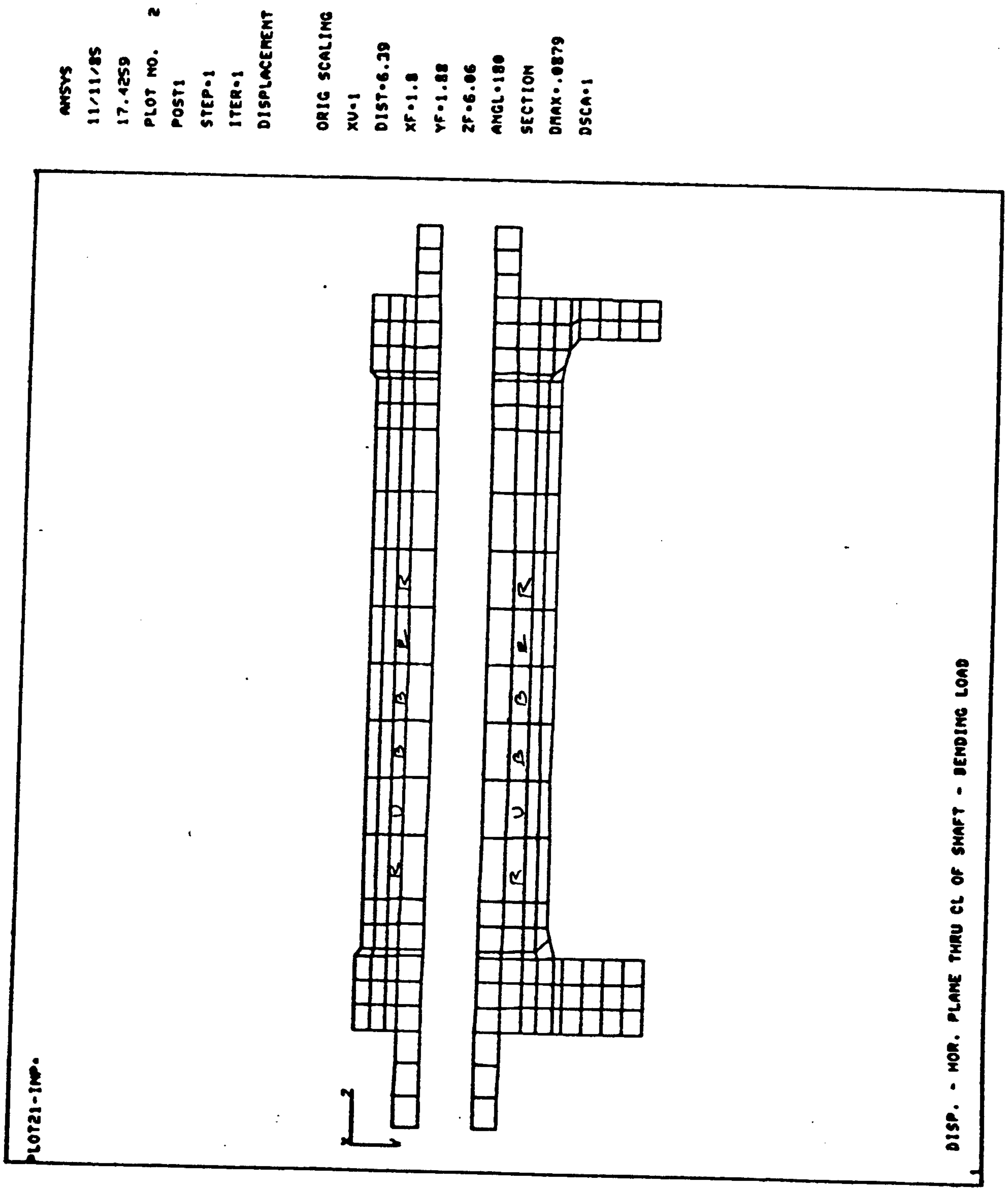


Figure 5-23 - Displacements, Plane 1, Out-of-Plane Load, Case 2
Displacements to Scale, Scale = 1.0

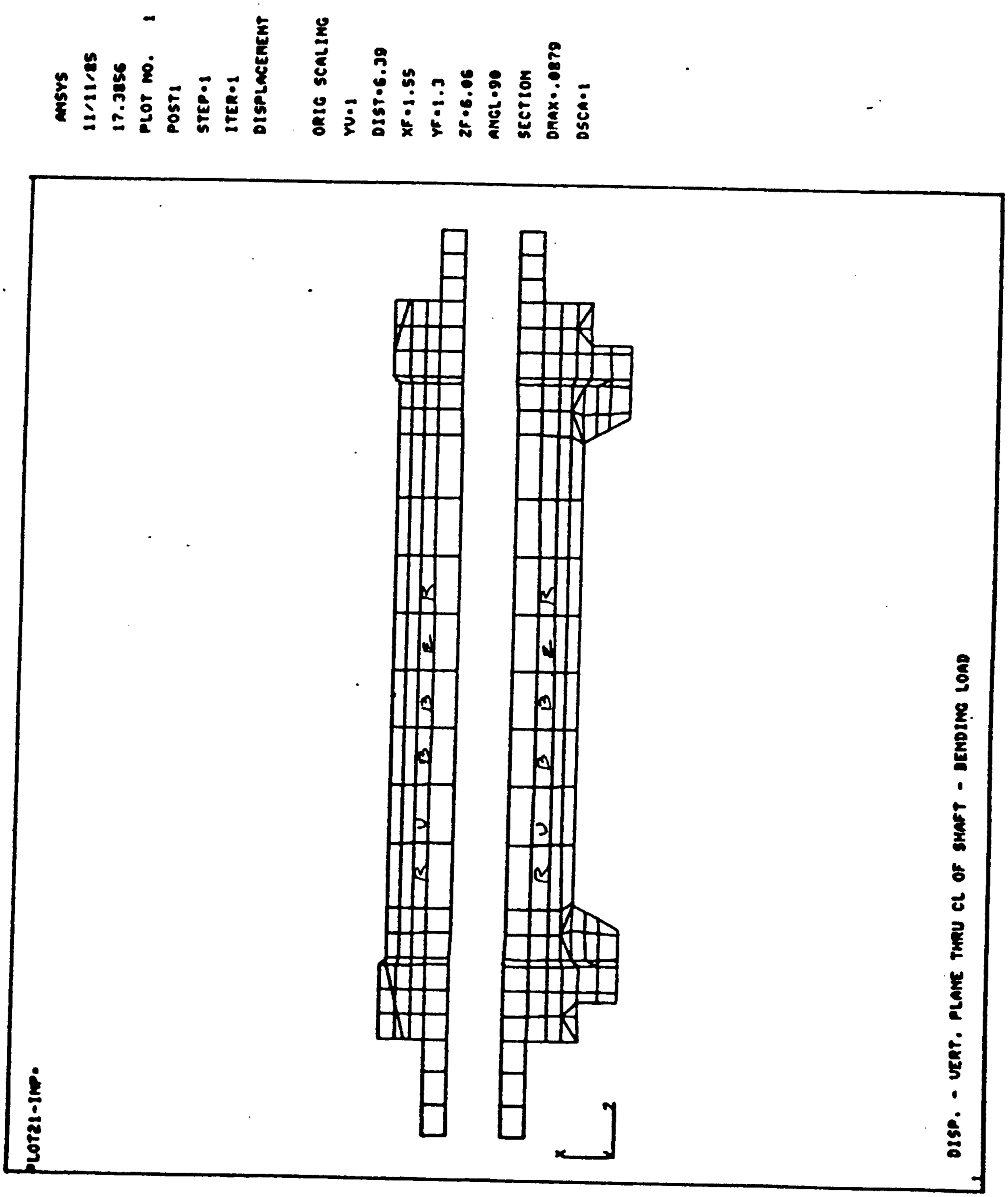


Figure 5-24 - Displacements, Plane 2, Out-of-Plane Load, Case 2

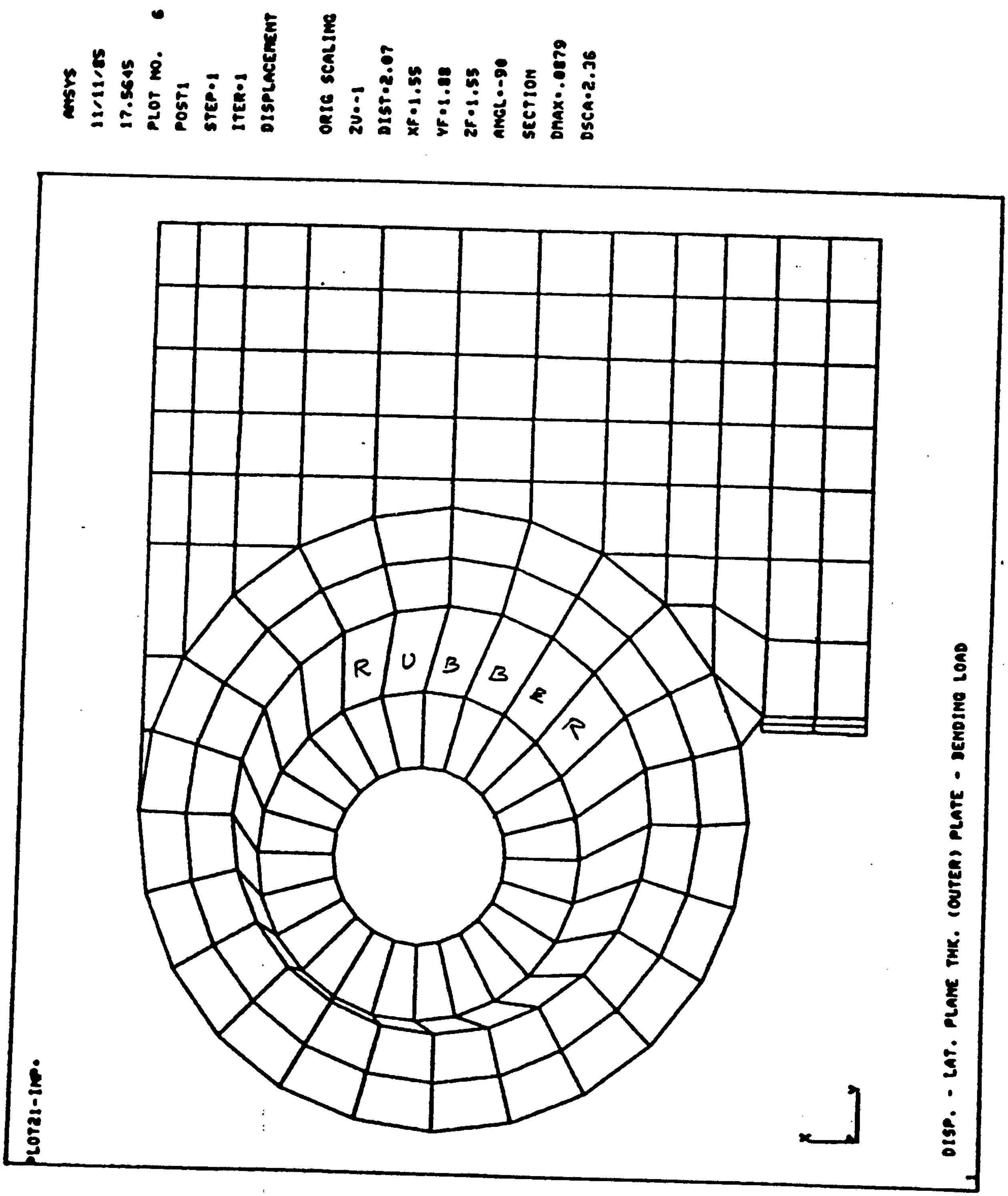


Figure 5-25 - Displacements, Plane 3, Out-of-Plane Load, Case 2

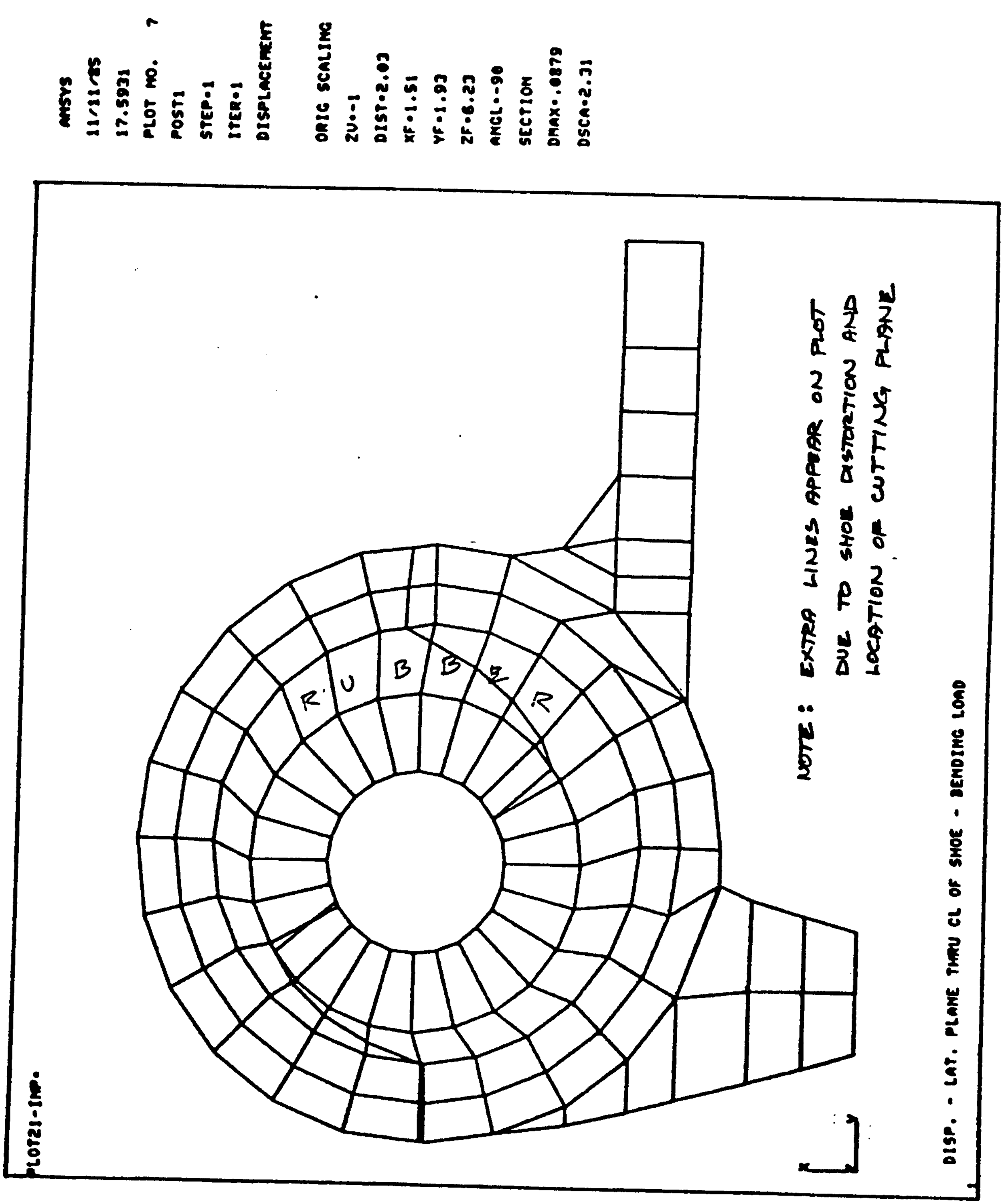


Figure 5-26 - Displacements, Plane 4, Out-of-Plane Load, Case 2

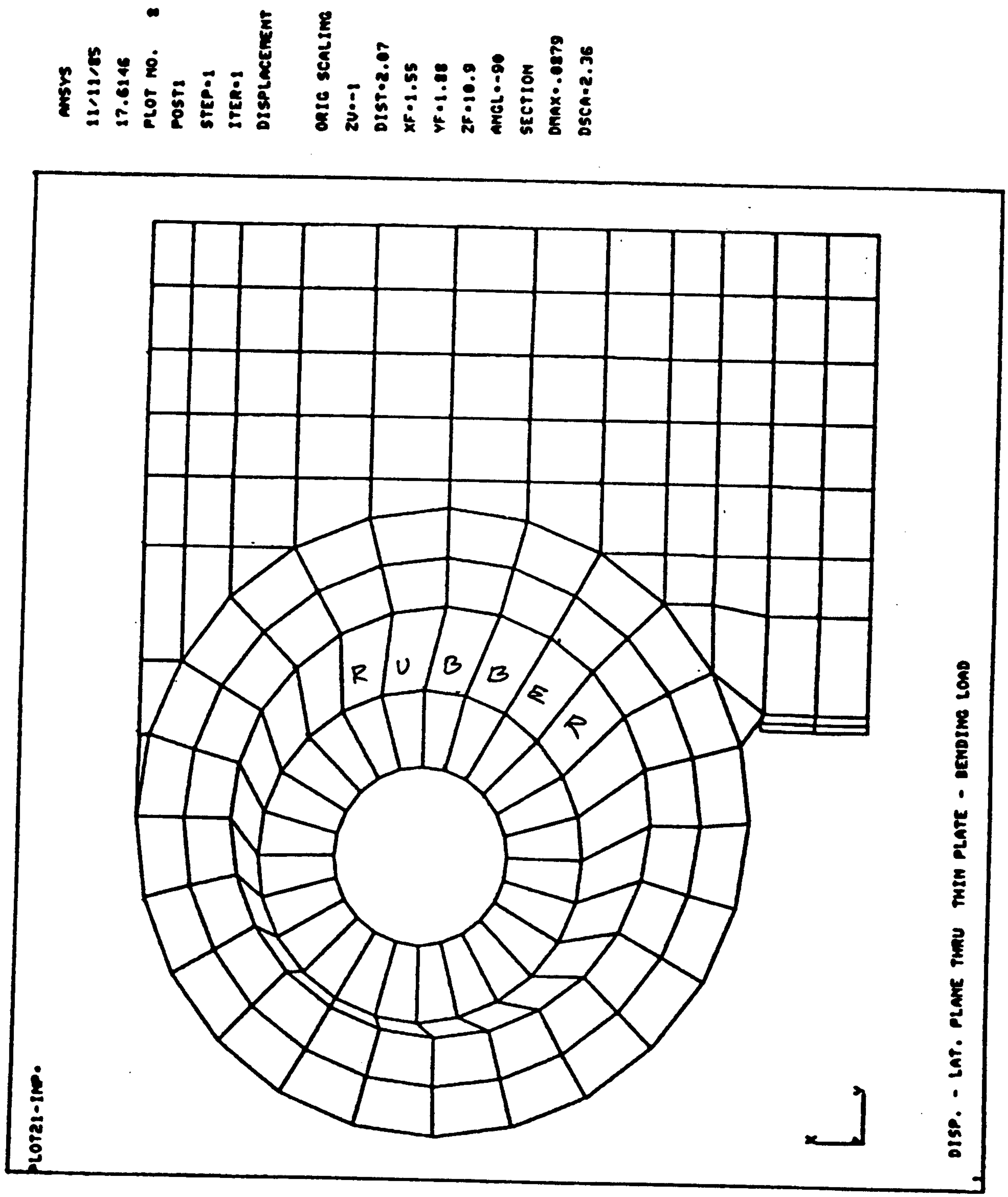


Figure 5-27 - Displacements, Plane 5, Out-of-Plane Load, Case 2

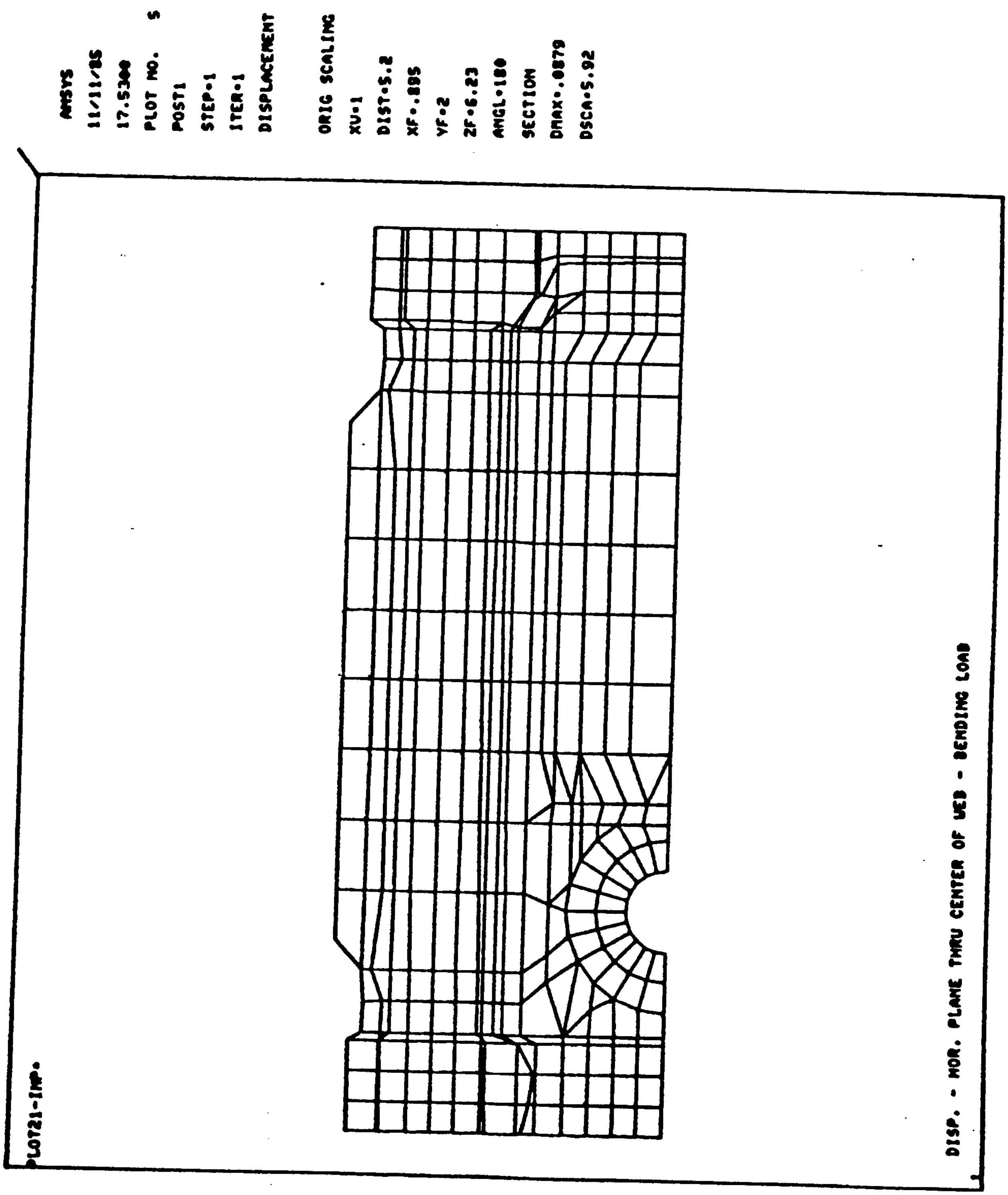


Figure 5-28 - Displacements, Plane 6, Out-of-Plane Load, Case 2

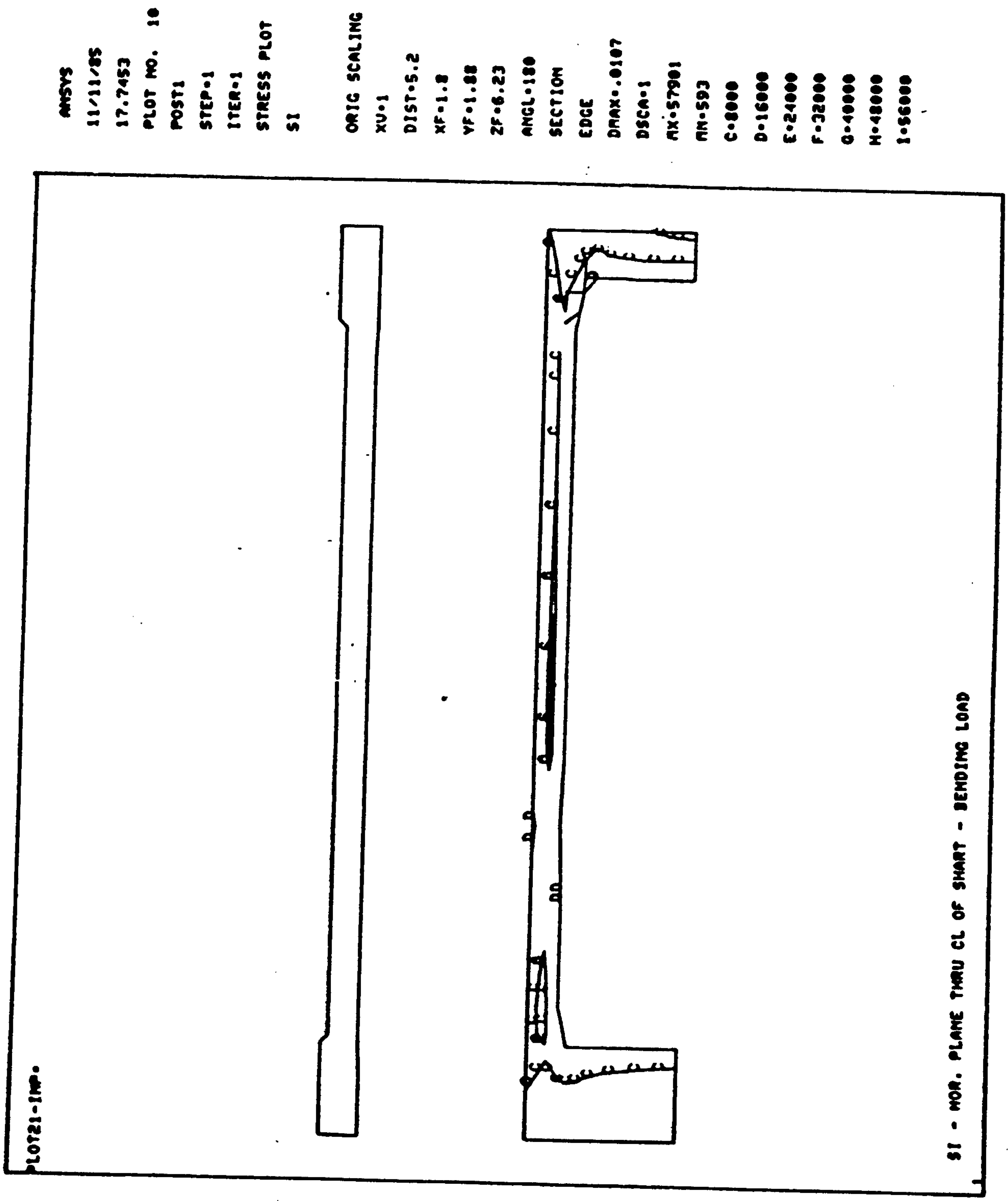


Figure 5-29 - Stress Intensity, Plane 1, Out-of-Plane Load, Case 2

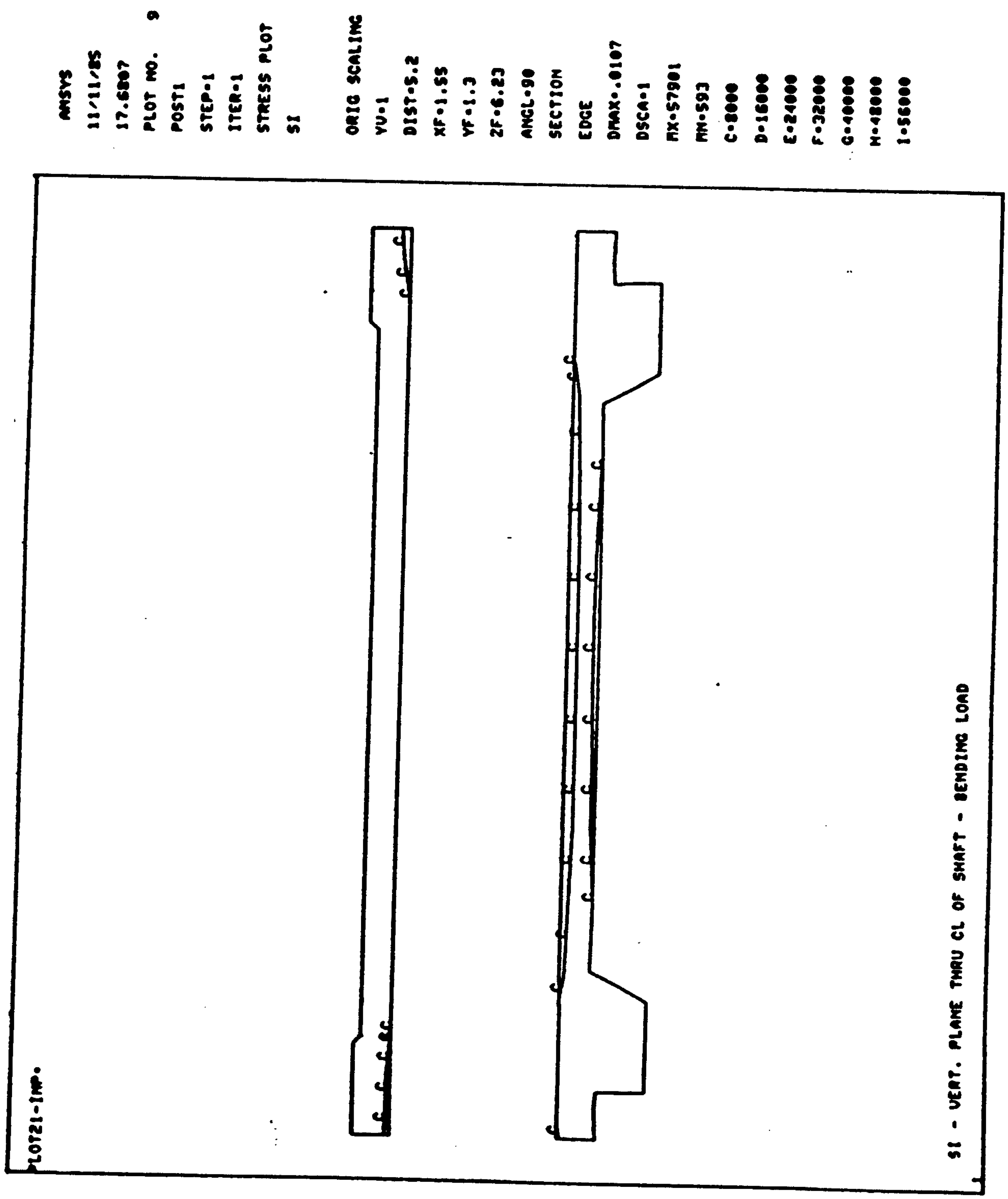


Figure 5-30 - Stress Intensity, Plane 2, Out-of-Plane Load, Case 2

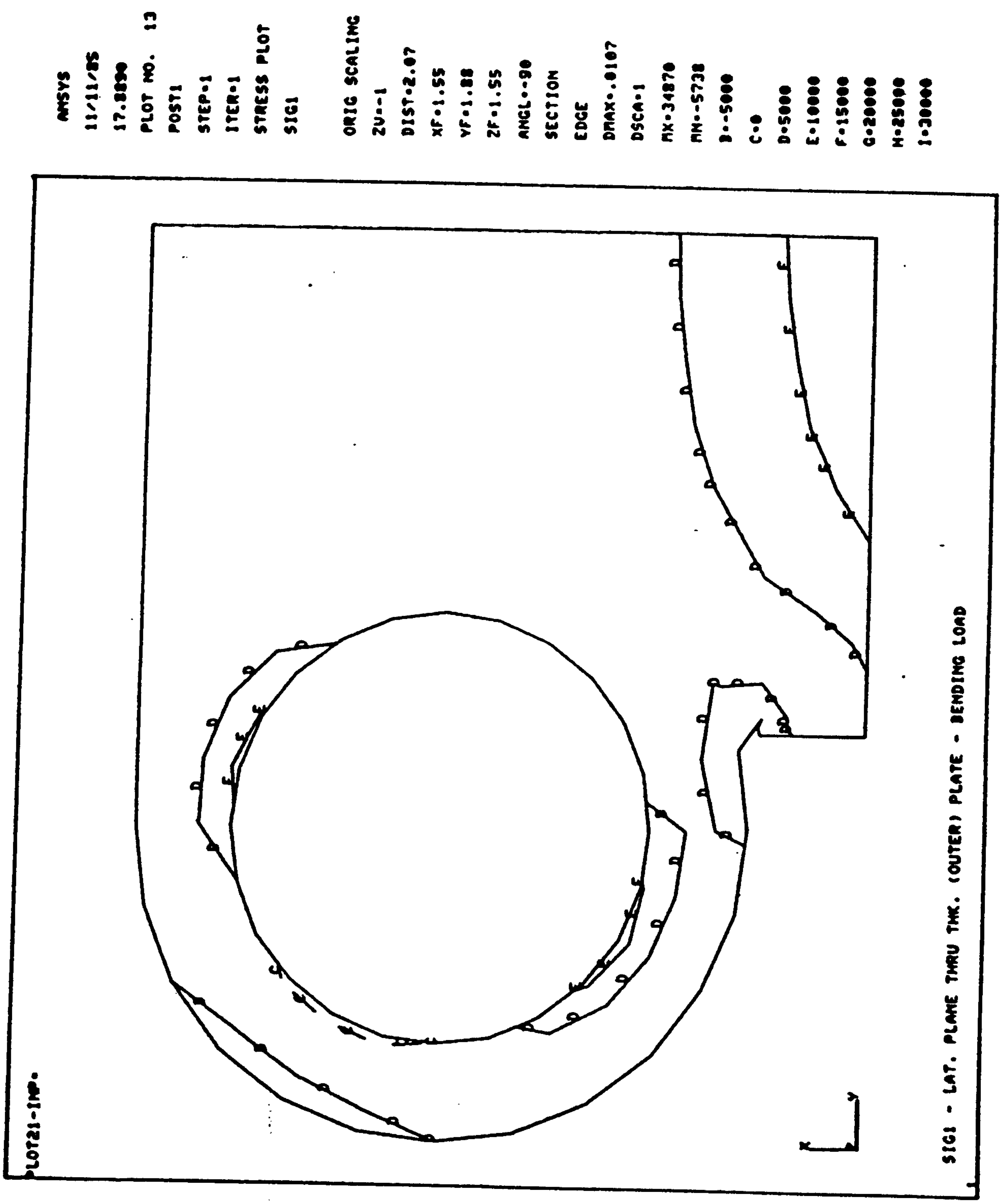


Figure 5-31 - SIG1 Principal Stress, Plane 3, Out-of-Plane Load, Case 2

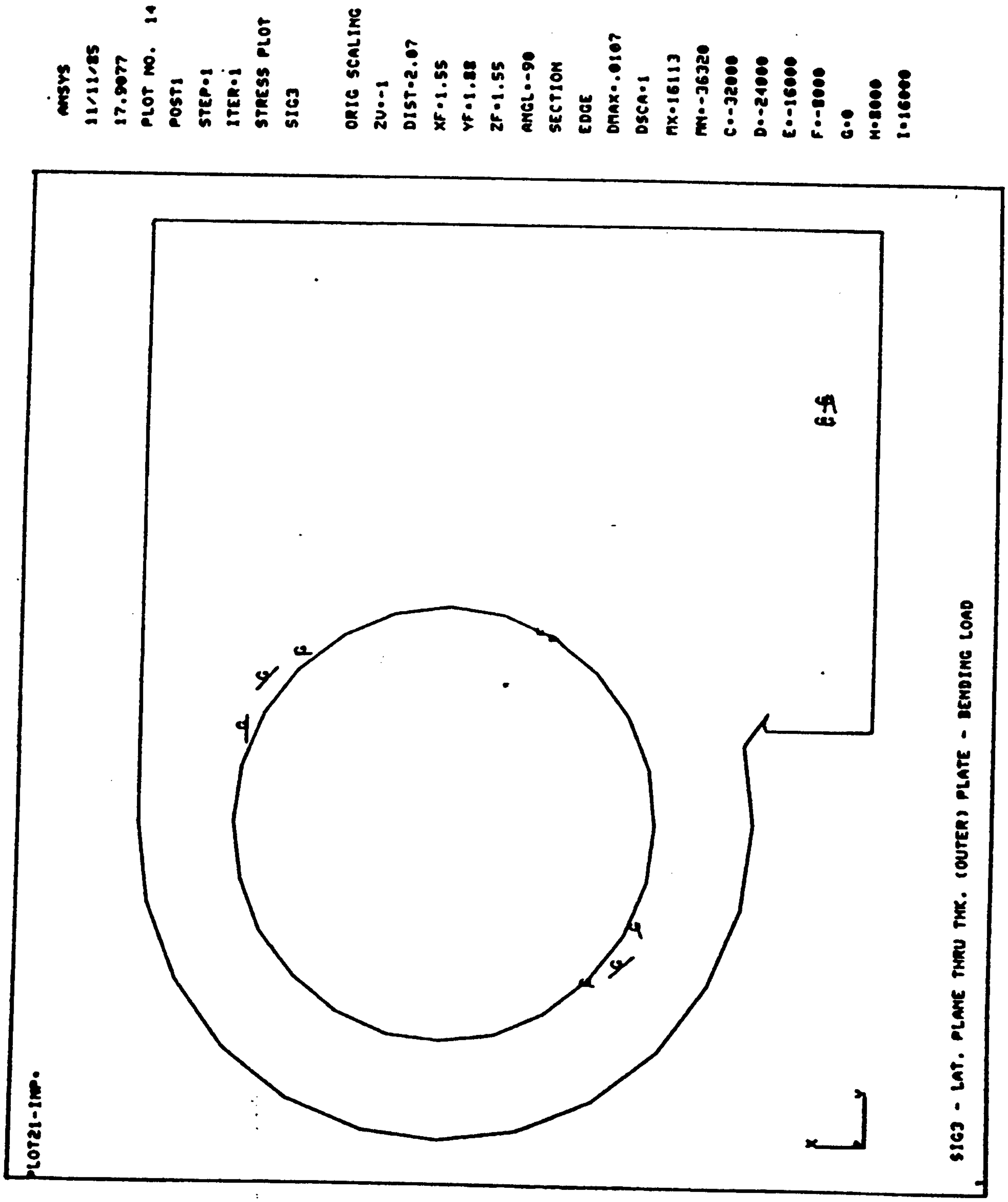


Figure 5-32 - SIG3 Principal Stress, Plane 3, Out-of-Plane Load, Case 2

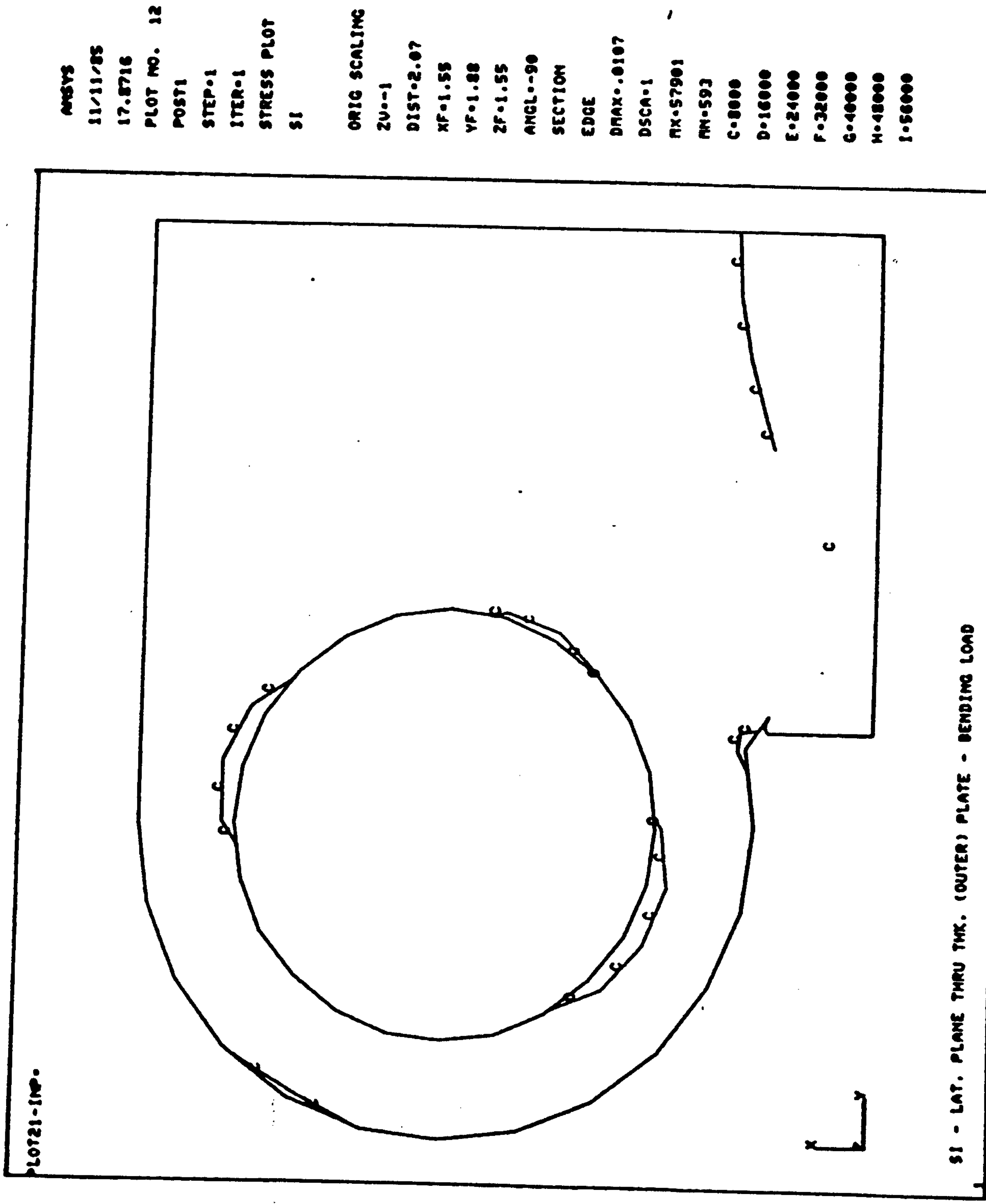


Figure 5-33 - Stress Intensity, Plane 3, Out-of-Plane Load, Case 2

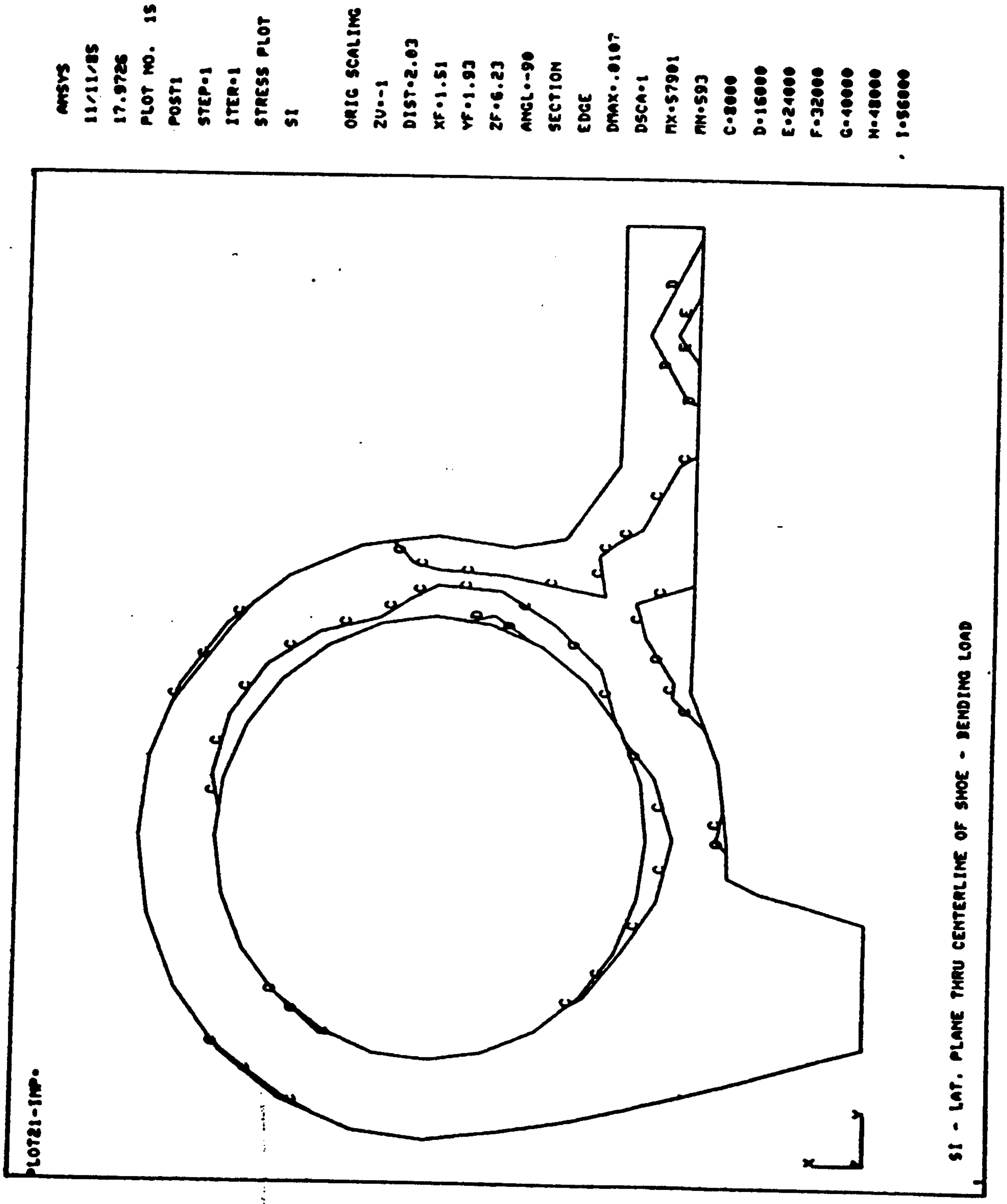


Figure 5-34 - Stress Intensity, Plane 4, Out-of-Plane Load, Case 2

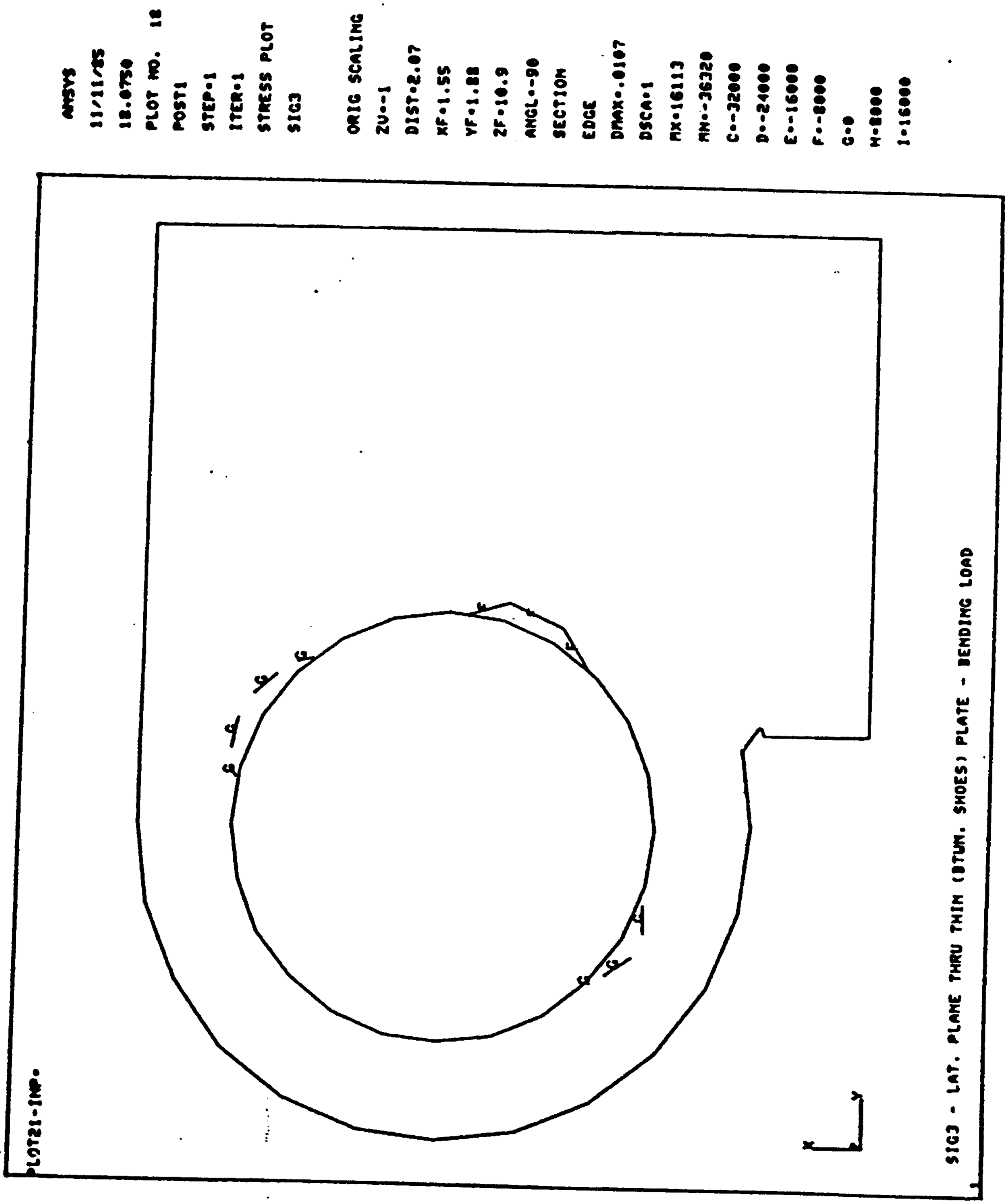


Figure 5-36 - SIG3 Principal Stress, Plane 5, Out-of-Plane Load, Case 2

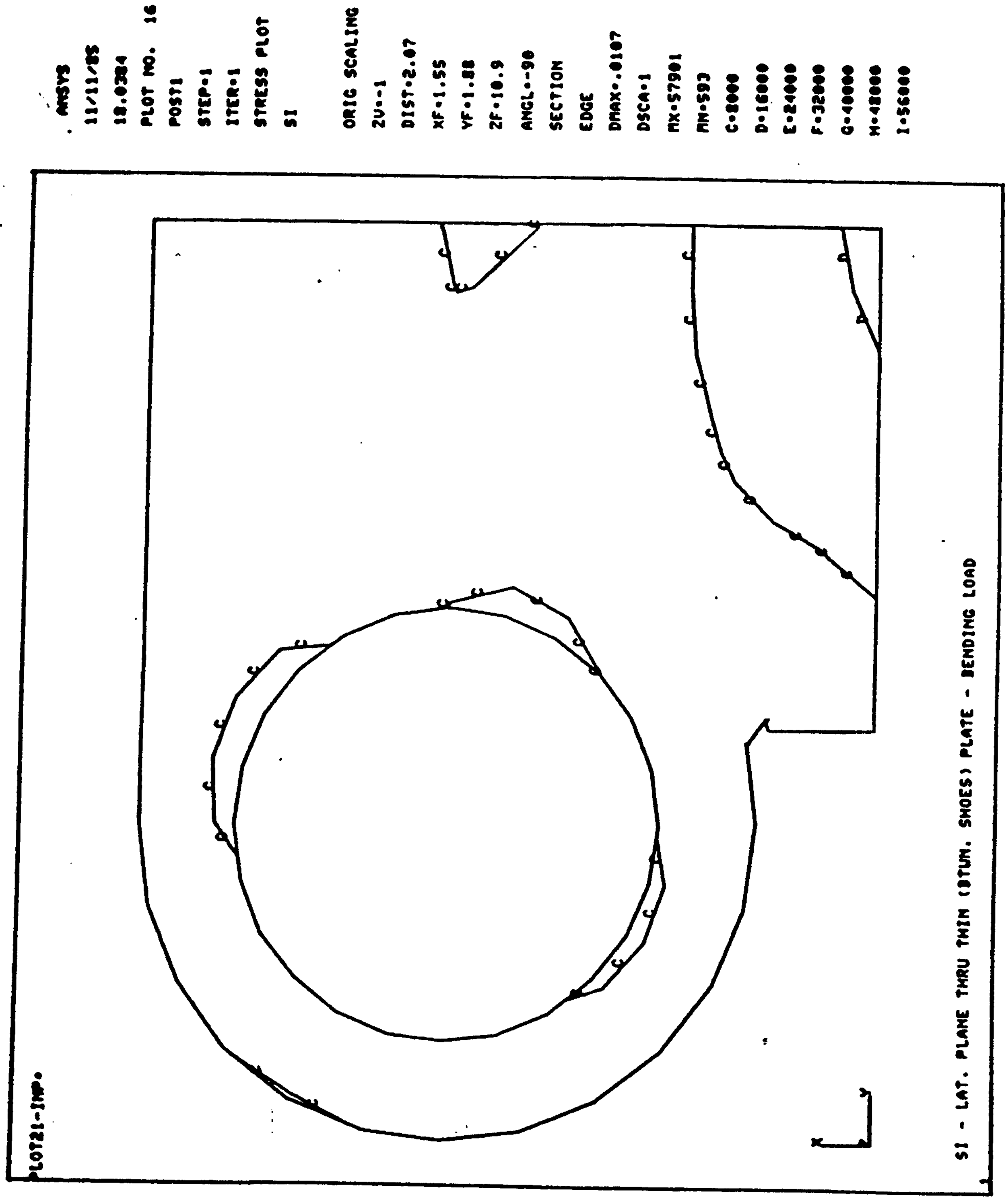


Figure 5-37 - Stress Intensity, Plane 5, Out-of-Plane Load, Case 2

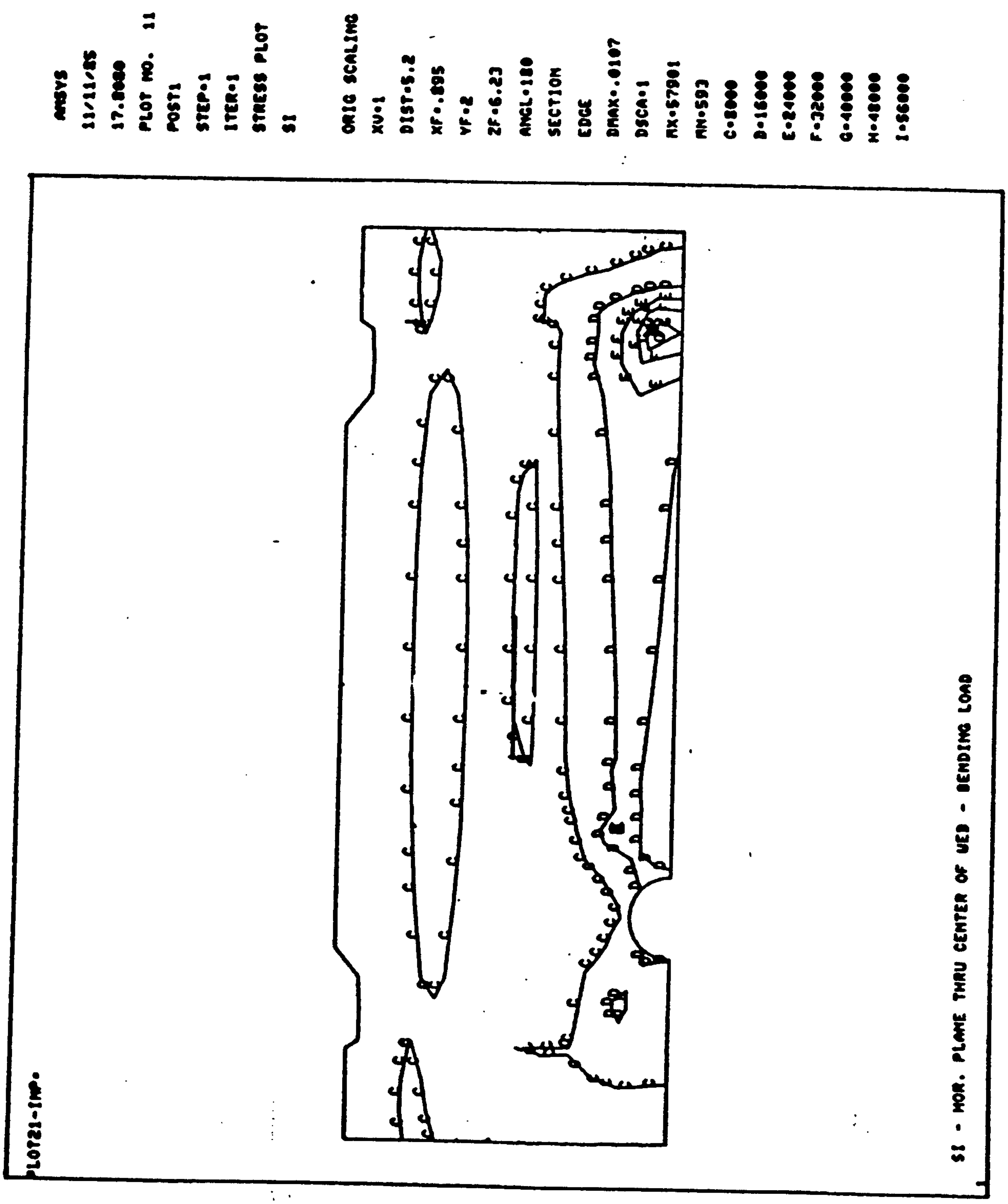


Figure 5-38 - Stress Intensity, Plane 6, Out-of-Plane Load, Case 2

5.4 Twisting Load

This section presents the results for Case 3, a twisting load on the shoe, as illustrated in Figure 3-3. The format used to present these results is identical to that of the two previous sections and is summarized below:

Tables 5-24 to 5-30:	Maximum stress summaries
Table 5-31:	Shaft and rubber displacements
Figures 5-39 to 5-44:	Displacement plots
Figures 5-45 to 5-54:	Stress contour plots

TABLE 5-24
Maximum Stress Summary
Type 1 - Steel Shaft
Twisting Load, Case 3

ERSE FOR LABEL- TYPE FROM 1 TO 1 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
537	7931.0443	-887.32205	-153489.48	161420.52	157198.96
6	153344.03	859.16034	-7932.9328	161276.96	157065.58
538	-16251.547	-23720.950	-175681.57	159430.02	156829.64
2	175533.52	23772.004	16256.410	159277.11	156665.45
4	152777.90	2676.2447	-6221.3126	158999.21	154742.41
522	6225.6400	-2672.4808	-152603.81	158829.46	154578.60
1	173016.95	30266.925	14221.076	158795.87	151411.96
523	-14293.211	-30261.248	-172852.33	158559.12	151208.78
482	8657.0468	1344.3290	-145825.85	154482.90	150959.44
8	145387.59	-1361.4403	-8668.4409	154056.03	150536.60
483	-12661.422	-18262.813	-166573.51	153912.09	151189.24
7	166080.29	18214.199	12693.681	153386.61	150702.20
3	158586.97	34668.010	10034.697	148552.27	137895.77
447	-10048.479	-34653.494	-158073.51	148025.03	137385.07
5	143470.81	3674.9380	-3350.4622	146821.27	143437.66

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
537	1	45	1	337	187	163	313	338	188	164	314
6	1	45	1	326	176	152	302	327	177	153	303
538	1	45	1	187	37	13	163	188	38	14	164
2	1	45	1	176	26	2	152	177	27	3	153
4	1	45	1	349	199	175	325	326	176	152	302
522	1	45	1	338	188	164	314	339	189	165	315
1	1	45	1	199	49	25	175	176	26	2	152
523	1	45	1	188	38	14	164	189	39	15	165
482	1	45	1	336	186	162	312	337	187	163	313
8	1	45	1	327	177	153	303	328	178	154	304
483	1	45	1	186	36	12	162	187	37	13	163
7	1	45	1	177	27	3	153	178	28	4	154
3	1	45	1	198	48	24	174	199	49	25	175
447	1	45	1	189	39	15	165	190	40	16	166
5	1	45	1	348	198	174	324	349	199	175	325

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
188	19609.268	-10063.761	-229304.16	248913.43	235543.35
176	229316.04	10049.584	-19596.906	248912.95	235553.54
187	19843.241	-12500.803	-226195.37	246138.61	231720.37
177	225743.16	12372.226	-19930.289	245673.45	231312.91
199	218071.32	6766.0965	-15071.826	233143.14	223102.21
189	15073.002	-6659.5120	-217591.89	232664.89	222669.15
26	265441.55	59300.804	37825.204	227616.34	217746.49
38	-37845.426	-59274.901	-265442.37	227596.94	217744.59
37	-37267.741	-55086.289	-263902.57	226634.83	218359.60
27	263397.33	55000.328	37290.010	226107.32	217843.16
186	16684.234	-13042.040	-208057.56	224741.79	211603.57
178	207204.80	12937.539	-16646.356	223851.15	210775.22
36	-26647.295	-49691.973	-242734.32	216087.03	205715.98
49	247533.58	59147.422	31892.835	215640.74	203644.58
28	241778.53	49546.064	26653.352	215125.18	204820.75

TABLE 5-25
Maximum Stress Summary
Type 2 - Rubber Bushing
Twisting Load, Case 3

ERSE FOR LABEL= TYPE FROM 2 TO 2 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
223	1644.0919	-0.69628300	-1431.4169	3075.5087	2665.6185
169	1395.8123	1.3662067	-1677.4239	3073.2362	2665.2952
277	1857.0135	-2.7058252	-1165.6158	3022.6293	2640.7578
86	1130.5973	3.4922985	-1885.7629	3016.3602	2639.8939
225	1597.7825	-1.0551005	-1375.3995	2973.1820	2577.2966
171	1363.4800	0.87640614	-1609.2175	2972.6975	2577.4039
2585	1613.3153	0.68939972E-01	-1350.0908	2963.4060	2569.7539
2477	1345.1657	-0.15779253	-1617.3021	2962.4679	2569.1698
2681	1854.3883	0.31379888	-1072.9331	2927.3214	2565.0206
2432	1068.2625	-0.36020078	-1856.3110	2924.5735	2563.1658
279	1798.7395	-2.8918633	-1123.8352	2922.5747	2553.8043
88	1112.0799	2.7699909	-1809.0663	2921.1462	2554.0570
337	2018.0672	-4.6813782	-898.50682	2916.5740	2588.1306
40	866.70185	5.6172023	-2041.1233	2907.8252	2587.0892
175	1324.0116	0.63624083E-01	-1535.6515	2859.6631	2478.8034

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
223	2	45	2	656	506	482	632	657	507	483	633
169	2	45	2	655	505	481	631	656	506	482	632
277	2	45	2	657	507	483	633	658	508	484	634
86	2	45	2	654	504	480	630	655	505	481	631
225	2	45	2	806	656	632	782	807	657	633	783
171	2	45	2	805	655	631	781	806	656	632	782
2585	2	45	2	3518	3368	3344	3494	3519	3369	3345	3495
2477	2	45	2	3517	3367	3343	3493	3518	3368	3344	3494
2681	2	45	2	3519	3369	3345	3495	3520	3370	3346	3496
2432	2	45	2	3516	3366	3342	3492	3517	3367	3343	3493
279	2	45	2	807	657	633	783	808	658	634	784
88	2	45	2	804	654	630	780	805	655	631	781
337	2	45	2	658	508	484	634	659	509	485	635
40	2	45	2	653	503	479	629	654	504	480	630
175	2	45	2	955	805	781	931	956	806	782	932

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
482	1722.7969	-0.74237382E-03	-1772.2173	3495.0142	3029.3636
483	1987.7635	-4.6948113	-1480.3206	3468.0841	3017.1797
481	1430.6537	4.6948496	-2032.6417	3463.2955	3017.4869
3494	1711.6627	0.39507139E-01	-1718.4351	3430.0978	2973.1290
3495	2010.3687	1.4061253	-1402.5081	3412.8768	2973.8103
3493	1395.5185	-1.3267380	-2015.3664	3410.8849	2972.7103
632	1685.6392	0.58377677E-02	-1710.7680	3396.4072	2943.7447
484	2204.5280	-9.1003688	-1178.6636	3383.1916	2979.0906
480	1132.9984	9.1344396	-2241.8263	3374.8247	2979.5393
633	1937.2156	-4.3763410	-1432.6377	3369.8534	2932.1258
631	1407.3144	4.3839498	-1960.1149	3367.4293	2932.2658
3496	2270.4443	2.6619936	-1088.4467	3358.8910	2970.8657
3492	1082.6201	-2.5789570	-2272.3631	3354.9832	2968.3084
634	2143.2388	-8.4741904	-1145.2930	3288.5318	2895.6698
630	1121.8543	8.5003712	-2162.5184	3284.3727	2895.9780

TABLE 5-26
Maximum Stress Summary
Type 3 - Shoe Binocular
Twisting Load, Case 3

ERSE FOR LABEL= TYPE FROM 3 TO 3 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
655	39783.982	3197.5361	-473.69918	40257.681	38553.385
656	40187.933	3748.3815	1304.9422	38862.990	37700.704
654	34955.959	1772.2762	-2199.1010	37155.060	35337.142
774	31816.441	74.778555	-2629.9564	34446.397	33176.822
657	36139.393	4393.2127	1716.7043	34422.689	33165.533
775	32208.052	442.37699	-1743.0396	33951.092	32912.846
902	28839.078	-254.35966	-4651.6477	33490.726	31522.952
773	29160.815	297.68520	-3866.2287	33027.043	31154.486
903	28933.742	-169.89880	-4028.9806	32962.722	31212.622
901	26746.081	-196.89393	-5765.1706	32511.251	30115.702
776	29646.476	1106.3357	-1910.5894	31557.066	30161.978
904	26708.768	-66.997724	-4322.9061	31031.674	29137.770
2454	15512.386	-15.858490	-15002.959	30515.345	26428.449
772	25464.455	1631.3852	-4895.6749	30360.130	27679.914
838	23084.360	-767.94605	-7266.7255	30351.086	27679.912

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
655	3	45	3	1174	1024	1000	1150	1175	1025	1001	1151
656	3	45	3	1175	1025	1001	1151	1176	1026	1002	1152
654	3	45	3	1173	1023	999	1149	1174	1024	1000	1150
774	3	45	3	1324	1174	1150	1300	1325	1175	1151	1301
657	3	45	3	1176	1026	1002	1152	1177	1027	1003	1153
775	3	45	3	1325	1175	1151	1301	1326	1176	1152	1302
902	3	45	3	1474	1324	1300	1450	1475	1325	1301	1451
773	3	45	3	1323	1173	1149	1299	1324	1174	1150	1300
903	3	45	3	1475	1325	1301	1451	1476	1326	1302	1452
901	3	45	3	1473	1323	1299	1449	1474	1324	1300	1450
776	3	45	3	1326	1176	1152	1302	1327	1177	1153	1303
904	3	45	3	1476	1326	1302	1452	1477	1327	1303	1453
2454	3	45	3	2239	2089	2065	2215	2240	2090	2066	2216
772	3	45	3	1322	1172	1148	1298	1323	1173	1149	1299
838	3	45	3	1449	1299	1251	1401	1450	1300	1252	1402

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1175	41343.995	1242.2046	-5250.3814	46594.376	43729.429
1176	41089.252	2411.9777	-5132.0563	46221.308	42990.512
1174	36960.372	-325.59097	-4994.8376	41955.209	39862.175
1325	39119.070	945.12582	-2537.2997	41656.370	40030.741
1182	22542.397	2422.9468	-18694.476	41236.873	35769.636
1326	38601.853	1452.7235	-1904.6408	40506.494	38947.541
1177	35415.318	1493.1030	-4901.7673	40317.086	37565.316
1324	36108.559	163.94523	-3957.4667	40066.026	38186.998
1024	38403.907	6521.5166	-1017.5081	39421.415	36322.323
1025	38680.093	8896.8991	-197.81595	38877.909	35540.995
1332	12647.674	-2112.2728	-25806.150	38453.824	33853.791
1323	31477.715	-42.465699	-6208.0622	37685.777	35020.416
2082	14345.425	-2312.2410	-23335.840	37681.265	32904.370
1327	33564.615	1048.0032	-2441.4079	35996.023	34428.366
1482	5824.2942	-2951.7807	-29899.462	35723.756	32288.417

TABLE 5-27
Maximum Stress Summary
Type 4 - Shoe End Plates
Twisting Load, Case 3

ERSE FOR LABEL= TYPE FROM 4 TO 4 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
201	34027.961	5156.7030	2335.5121	31692.449	30380.256
420	9080.4965	-5043.2410	-20421.178	29501.675	25560.894
206	26380.526	3893.8553	-1658.6594	28039.186	25716.500
210	29363.945	7728.7884	2613.7847	26750.161	24594.861
2397	13621.616	34.624552	-12951.701	26473.317	22927.832
2398	13416.070	58.244404	-12922.579	26338.650	22810.719
2379	14084.372	247.16140	-12203.856	26288.228	22776.821
207	26386.912	1692.8139	148.92650	26237.985	25501.117
463	12837.520	-60.798972	-13358.577	26196.098	22687.366
2380	13805.855	218.68770	-12257.727	26143.582	22640.833
301	12207.783	-207.26947	-13876.644	26084.427	22598.481
2356	14646.292	322.22034	-11221.547	25867.840	22445.097
321	11324.725	-197.05638	-14382.379	25707.104	22302.802
2351	14319.364	309.40895	-11334.818	25654.182	22248.640
460	12634.461	-41.032354	-12991.326	25625.788	22193.008

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
201	4	45	3	4235	4248	874	873	4352	4365	1024	1023
420	4	45	3	882	1031	881	881	4264	4264	4264	4264
206	4	45	3	874	4262	4263	875	1024	4379	4380	1025
210	4	45	3	875	4263	876	876	1025	4380	1026	1026
2397	4	45	3	4818	4831	4832	4819	4935	4948	4949	4936
2398	4	45	3	4819	4832	4833	4820	4936	4949	4950	4937
2379	4	45	3	4805	4818	4819	4806	4922	4935	4936	4923
207	4	45	3	4248	4261	4262	874	4365	4378	4379	1024
463	4	45	3	4084	4097	4098	4085	4201	4214	4215	4202
2380	4	45	3	4806	4819	4820	4807	4923	4936	4937	4924
301	4	45	3	4071	4084	4085	4072	4188	4201	4202	4189
2366	4	45	3	4792	4805	4806	4793	4909	4922	4923	4910
321	4	45	3	4058	4071	4072	4059	4175	4188	4189	4176
2361	4	45	3	4793	4806	4807	4794	4910	4923	4924	4911
460	4	45	3	4083	4096	4097	4084	4200	4213	4214	4201

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
4250	-1772.6652	-6031.3022	-44711.024	42938.359	41071.113
1025	44759.252	11875.816	3771.9105	40987.342	37599.677
4260	-3134.9141	-4632.6552	-41989.468	38854.554	38127.752
4365	31431.088	-1261.1522	-5813.7675	37244.856	35244.509
4352	38722.442	4456.3507	1789.0216	36933.420	35675.681
4267	121.75319	-2922.4332	-36669.981	36791.734	35368.353
4949	18407.480	301.40281	-17108.990	35516.471	30760.195
4936	18734.653	180.90250	-16545.737	35280.390	30571.115
3275	-2004.3268	-6028.2011	-37271.148	35266.821	33455.882
4948	18176.418	160.83238	-16795.969	34972.387	30291.680
1023	37604.771	6168.3303	2797.0939	34807.677	33253.266
4935	18861.018	16.598083	-15802.138	34663.156	30064.564
4923	19769.983	539.45516	-14673.111	34443.094	29906.666
4950	17625.097	365.70567	-16309.736	33934.834	29389.878
4937	17731.168	174.36508	-16012.782	33743.960	29233.063

TABLE 5-28
Maximum Stress Summary
Type 5 - Shoe Rib and Wall
Twisting Load, Case 3

ERSE FOR LABEL= TYPE FROM 5 TO 5 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
2232	14923.293	138.39513	-15067.214	29990.507	25973.393
1437	15049.313	184.41645	-14715.625	29764.938	25777.198
2229	14130.459	77.601455	-15074.436	29204.895	25298.151
1307	14714.691	213.91470	-13749.193	28463.884	24651.913
548	-2955.8449	-4554.9937	-30959.555	28003.710	27230.364
1048	3380.0850	138.05445	-24098.412	27478.497	26009.468
494	3932.3876	-2918.8585	-23505.721	27438.108	24734.675
1047	7277.7771	-4593.5604	-20120.153	27397.930	23797.587
549	-275.97548	-2677.4554	-27443.633	27167.657	26050.070
496	2045.7063	-2791.3500	-24877.946	26923.652	24860.590
2224	11900.312	49.794180	-14408.052	26308.365	22820.979
2064	12253.455	23.523151	-13472.613	25726.067	22288.421
1430	12155.031	75.228144	-13492.060	25647.091	22223.481
2060	12078.047	7.8032311	-13074.600	25152.647	21788.709
1175	13652.073	224.70453	-11427.662	25079.735	21737.813

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
2232	5	45	3	5531	2088	2089	2089	5534	2238	2239	2239
1437	5	45	3	5528	1938	1939	1939	5531	2088	2089	2089
2229	5	45	3	5534	2238	2239	2239	5537	2388	2389	2389
1307	5	45	3	5525	1788	1789	1789	5528	1938	1939	1939
548	5	45	3	5254	4260	4143	4143	5154	4259	4142	4142
1048	5	45	3	1485	1484	5218	5218	5065	5065	5065	5065
494	5	45	3	5157	5154	5153	5153	1033	882	883	883
1047	5	45	3	1484	5066	5218	5218	5065	5065	5065	5065
549	5	45	3	5257	5254	5253	5253	5157	5154	5153	5153
496	5	45	3	5154	4259	4142	4142	882	4258	4141	4141
2224	5	45	3	5537	2388	2389	2389	5540	2538	2539	2539
2064	5	45	3	5431	5434	2237	2087	5531	5534	2238	2088
1430	5	45	3	5428	5431	2087	1937	5528	5531	2088	1938
2060	5	45	3	5434	5437	2387	2237	5534	5537	2388	2238
1175	5	45	3	5522	1638	1639	1639	5525	1788	1789	1789

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
4259	-5020.6704	-11892.487	-43992.910	38972.240	36031.307
4258	2516.5560	-5724.4710	-34338.898	36855.454	33503.914
5531	16528.268	-193.83107	-17462.098	33990.366	29438.081
5534	16263.976	-95.890023	-17350.067	33614.043	29114.229
5528	16289.766	-262.01218	-17060.949	33350.715	28883.181
4260	1128.7674	-2653.9761	-31622.118	32750.885	31032.909
1183	12364.303	655.72967	-19983.015	32347.318	28476.678
5537	15006.801	-100.22080	-17013.616	32020.417	27746.647
2088	15263.288	-168.79309	-16246.069	31509.357	27289.908
5525	15722.078	-242.88967	-15688.083	31410.161	27204.256
2238	15045.192	-100.22542	-16167.222	31212.414	27034.734
1938	14981.483	-215.36454	-15833.064	30814.547	26687.052
5266	852.54937	-1375.0382	-29597.284	30449.834	29438.494
2089	15685.920	524.78507	-14449.328	30135.248	26098.058
2230	14843.284	233.96644	-14885.250	29728.534	25746.971

REPORT NO.	REV. NO.	PROJECT NO.	BY	DATE	CHEKD. BY	DATE	PAGE
DEAC-TR-120		ALC-85-003					103

TABLE 5-29
Maximum Stress Summary
Type 6 - Shoe Web
Twisting Load, Case 3

ERSE FOR LABEL= TYPE FROM 6 TO 6 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
676	16886.398	193.28930	-7984.0048	24870.403	21955.238
921	15932.061	4013.8934	-5220.0013	21152.062	18367.325
795	6882.4378	-86.660297	-14175.460	21057.898	18580.873
1043	14961.174	4179.1359	-5526.4130	20487.587	17750.933
922	6003.2170	-331.00331	-14167.240	20170.457	17866.325
1044	4894.9509	-17.897536	-14185.086	19080.037	17159.445
794	13430.129	1346.1165	-5634.8640	19064.993	16706.756
1134	4457.7306	-418.56484	-13749.546	18207.277	16324.801
1129	16032.341	4340.8380	-1721.3628	17753.704	15630.667
1260	4745.1736	-264.24162	-12295.318	17040.492	15169.367
1385	4963.3555	-270.49556	-11677.759	16641.115	14738.479
1186	14413.774	-794.88364	-1946.9352	16360.709	15816.183
1057	15505.377	3431.5506	-424.72616	15930.103	14394.727
1451	5422.2255	-190.73051	-10334.490	15756.715	13832.483
677	2945.5854	-2573.5321	-12180.289	15125.874	13257.875

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	. NODES							
676	6	45	3	4386	1031	1030	1030	6116	1181	1180	1180
921	6	45	3	6446	6447	1480	1330	6646	6647	1479	1329
795	6	45	3	6116	1181	1180	1180	6117	1331	1330	1330
1043	6	45	3	6447	6449	1630	1480	6647	6649	1629	1479
922	6	45	3	6117	1331	1330	1330	6118	1481	1480	1480
1044	6	45	3	6118	1481	1480	1480	6119	1631	1630	1630
794	6	45	3	6444	6446	1330	1180	6644	6646	1329	1179
1134	6	45	3	6119	1631	1630	1630	6120	1781	1780	1780
1129	6	45	3	6449	6451	1780	1630	6649	6651	1779	1629
1260	6	45	3	6120	1781	1780	1780	6121	1931	1930	1930
1385	6	45	3	6121	1931	1930	1930	6122	2081	2080	2080
1186	6	45	3	6433	6434	6449	6449	6633	6634	6649	6649
1057	6	45	3	6432	6433	6449	6447	6632	6633	6649	6647
1451	6	45	3	6122	2081	2080	2080	6123	2231	2230	2230
677	6	45	3	4399	6044	6116	4386	4398	6244	1180	1030

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
1479	22844.108	400.41397	-13034.690	35878.798	31433.990
1629	24674.662	-1608.9097	-10789.232	35463.894	31898.336
1329	24562.485	4447.7125	-10161.793	34724.278	30198.032
1779	28377.448	3318.7146	-4538.8808	32916.329	29775.549
6116	15465.404	3144.2035	-11297.512	26762.917	23901.557
6651	22705.739	1747.3715	-3726.6277	26432.367	24167.036
1179	14115.350	476.78724	-11841.698	25957.048	22530.115
4386	9351.7902	71.269838	-15834.611	25186.401	22062.584
6633	19622.057	330.55470	-5262.1097	24884.167	22670.280
1031	-8708.7534	-13141.294	-32620.077	23911.324	22032.043
6632	21655.626	586.94858	-1598.1445	23253.771	22251.646
1181	3202.8575	-2265.7247	-19889.571	23092.528	20914.073
6649	15541.001	-1295.8706	-7465.9902	23006.991	20657.581
4652	8074.4929	-2789.6764	-14817.176	22891.669	19930.084
6117	7564.9061	140.96593	-15177.639	22742.545	20114.794

TABLE 5-30
Maximum Stress Summary
Type 7 - Shoe Fillets
Twisting Load, Case 3

ERSE FOR LABEL= TYPE FROM 7 TO 7 BY 1

***** POST1 ELEMENT STRESS LISTING *****

ELEM	SIG1	SIG2	SIG3	SINT	SIGE
1255	23849.541	8122.3639	598.82418	23250.717	20549.253
1395	13867.670	3541.7398	-7134.9421	21002.612	18189.641
1994	3711.4091	-2715.7415	-15594.060	19305.470	17027.339
1265	13401.006	335.57512	-5643.5418	19044.547	16869.352
1983	3954.5358	-3298.0040	-13848.391	17802.927	15505.627
1254	11208.080	1444.0722	-4770.9311	15979.011	13951.539
1394	12098.694	2129.0042	-1934.5178	14033.211	12506.757
1713	4906.5878	-1075.3091	-9082.0628	13988.651	12156.758
1380	9798.8758	3444.5192	-3888.8126	13687.688	11863.988
1601	5592.4420	-724.92337	-8048.0470	13640.489	11823.709
1833	5647.5215	-777.96760	-7675.2757	13322.797	11540.292
1888	6955.0412	5.7963246	-5998.0662	12953.107	11227.675
1473	9007.4791	2534.5242	-3479.8140	12487.293	10816.744
1536	6104.6091	217.44270	-6221.8220	12326.431	10678.571
1876	7320.7997	129.37882	-4789.2487	12110.048	10548.998

***** POST1 ELEMENT LISTING *****

ELEM	TYPE	STIF	MAT	NODES							
1255	7	45	3	1780	6451	1779	1779	6651	6651	6651	6651
1395	7	45	3	6263	6264	7001	7001	6254	6254	6254	6254
1994	7	45	3	3279	3280	4663	4663	7009	7009	7009	7009
1265	7	45	3	6451	6453	6254	6254	7001	7001	7001	7001
1983	7	45	3	3279	3130	3129	3129	7009	7009	7009	7009
1254	7	45	3	1780	1930	1929	1779	6252	6262	7001	6451
1394	7	45	3	6264	6263	7001	7001	6270	6269	7002	7002
1713	7	45	3	6298	2830	2829	7007	6304	2980	2979	7008
1380	7	45	3	6262	1930	1929	7001	6268	2080	2079	7002
1601	7	45	3	6292	2680	2679	7006	6298	2830	2829	7007
1833	7	45	3	6304	2980	2979	7008	6310	3130	3129	7009
1888	7	45	3	6308	7018	6314	6314	6309	7019	6315	6315
1473	7	45	3	6268	2080	2079	7002	6274	2230	2229	7003
1536	7	45	3	6286	2530	2529	7005	6292	2680	2679	7006
1876	7	45	3	6307	7017	6313	6313	6308	7018	6314	6314

***** POST1 NODAL STRESS LISTING *****

NODE	SIG1	SIG2	SIG3	SI	SIGE
2829	10908.964	-104.06035	-15789.985	26698.949	23240.425
1929	19060.508	4446.6839	-7298.7759	26359.284	22884.387
2079	16485.612	161.68435	-8777.6322	25263.244	22190.080
2679	11304.426	280.57467	-13080.408	24384.834	21166.838
2229	14882.296	531.71119	-8714.6933	23596.989	20603.191
1779	20403.198	4610.9161	-2952.7209	23355.919	20641.025
6651	23849.541	8122.3639	598.82418	23250.717	20549.253
2529	12583.729	598.02029	-10565.450	23149.180	20069.235
2979	8787.8515	-409.78959	-14099.603	22887.454	19948.015
2379	13597.196	616.43686	-9259.0031	22856.199	19868.504
3129	5953.5564	-2345.9343	-14223.328	20176.884	17565.170
6254	13634.338	1938.6575	-6389.2419	20023.580	17529.497
6264	14269.926	3790.2380	-5530.3361	19800.262	17175.548
6453	13401.006	335.57512	-5643.5418	19044.547	16869.352
3279	3832.9725	-3007.2727	-14721.226	18554.198	16266.483

TABLE 5-31
Displacement Summary for Twisting Load, Case 3

SHAFT DISPLACEMENTS

LOCATION	NODES	ΔX (DISP)
Connector End	26, 38	.313839
Symmetry Plane	3926, 3928	0.

RUBBER DISPLACEMENTS

$NODE_i$	UX_i	$NODE_j$	UX_j	RELATIVE DISPLACEMENT $\Delta = UX_i - UX_j$
476	.302370	500	.206642	-.095728
926	.286337	950	.202494	-.083843
1976	.199404	2000	.181358	-.018046
3026	.078621	3050	.154676	+.076055
3476	.039370	3500	.148320	+.108950
512	.207334	488	.302371	+.095037
962	.203095	938	.286380	+.083285
2012	.182178	1988	.199407	+.017229
3062	.154412	3038	.078620	-.075792
3512	.147926	3488	.039369	-.108557

NOTES: (1) Refer to Figure 5-5 for node locations.
(2) Minus sign on relative displacements (Δ) means compression.

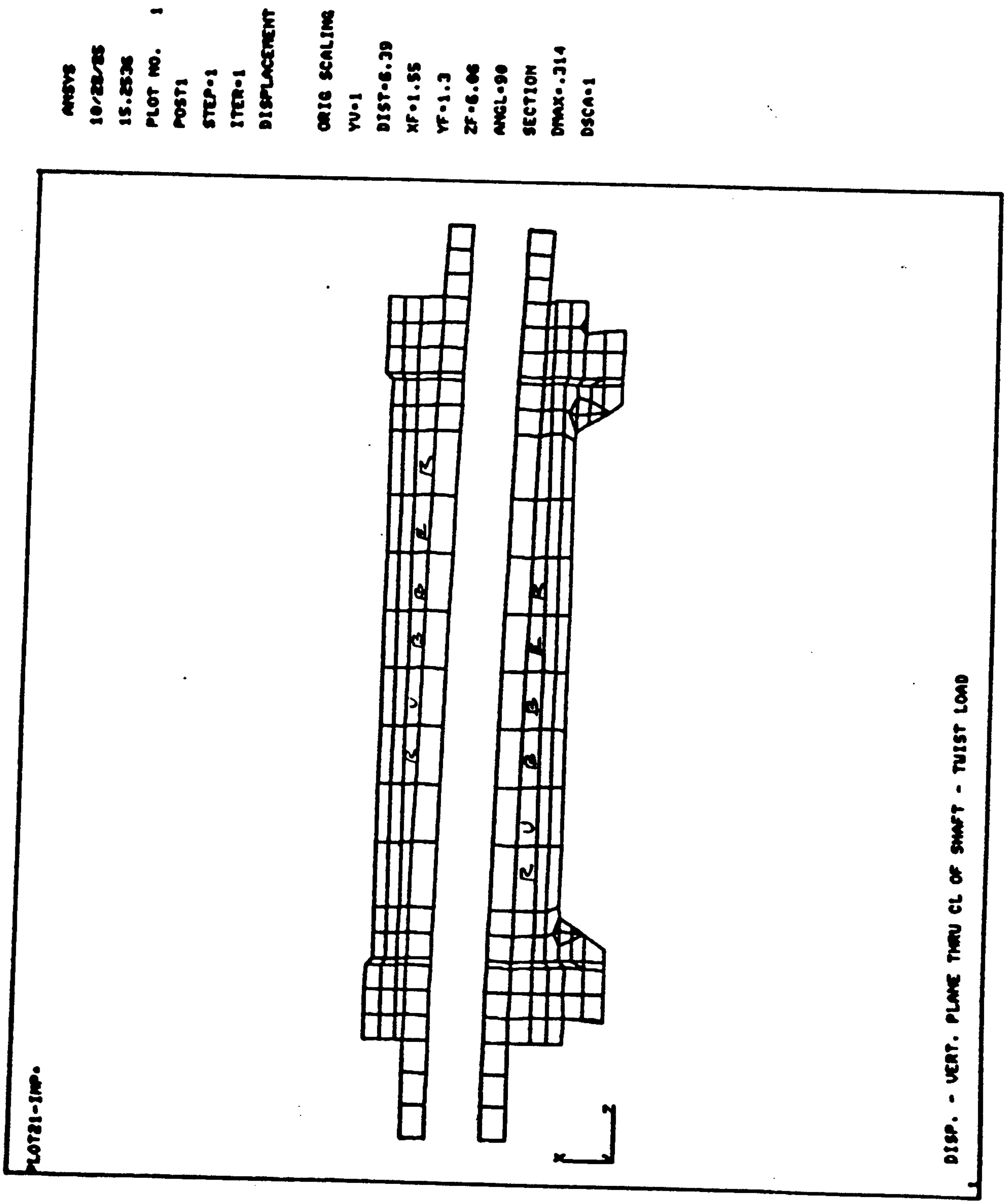


Figure 5-39 - Displacements, Plane 1, Twisting Load, Case 3
Displacements to Scale, Scale = 0

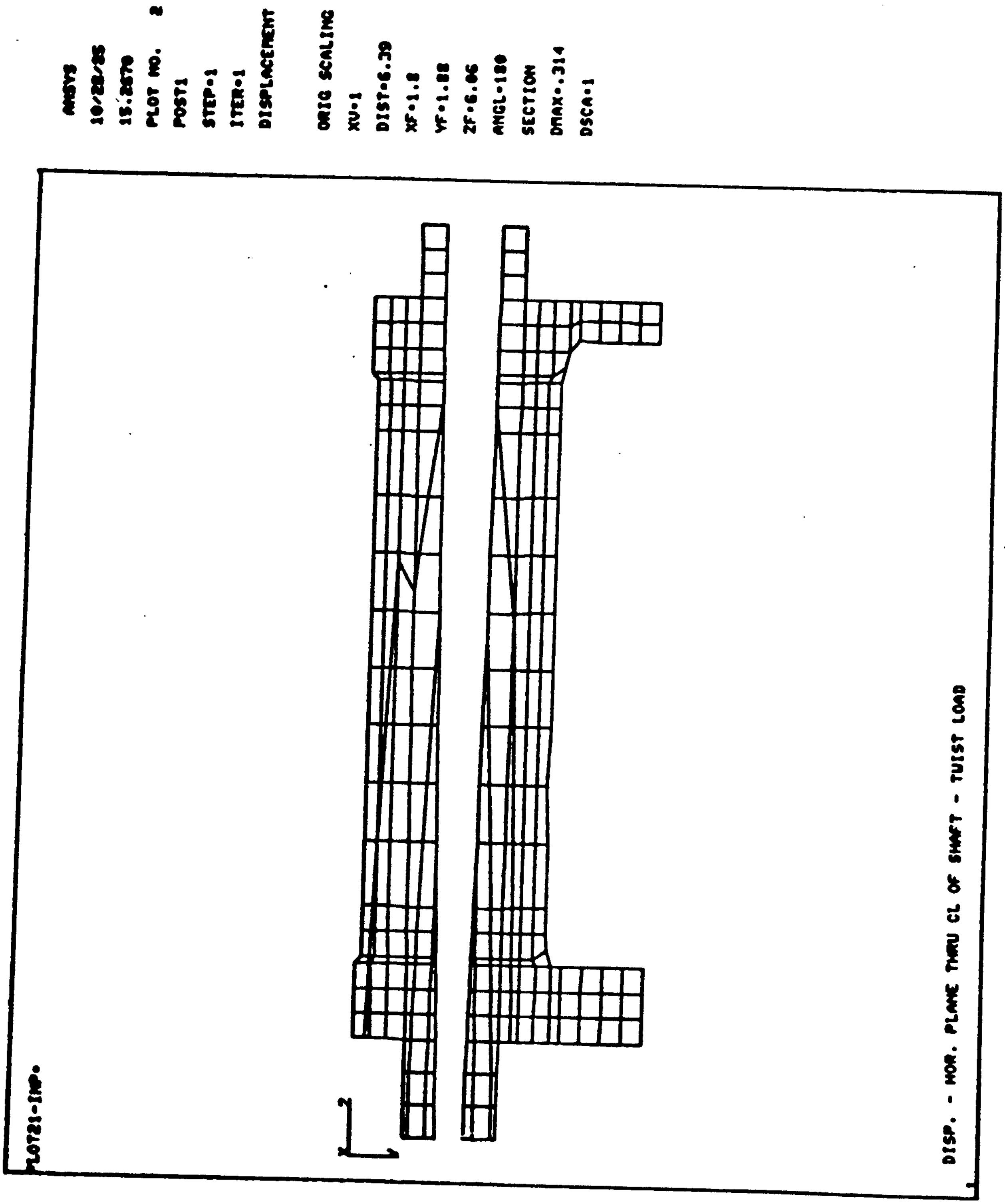


Figure 5-40 - Displacements, Plane 2, Twisting Load, Case 3

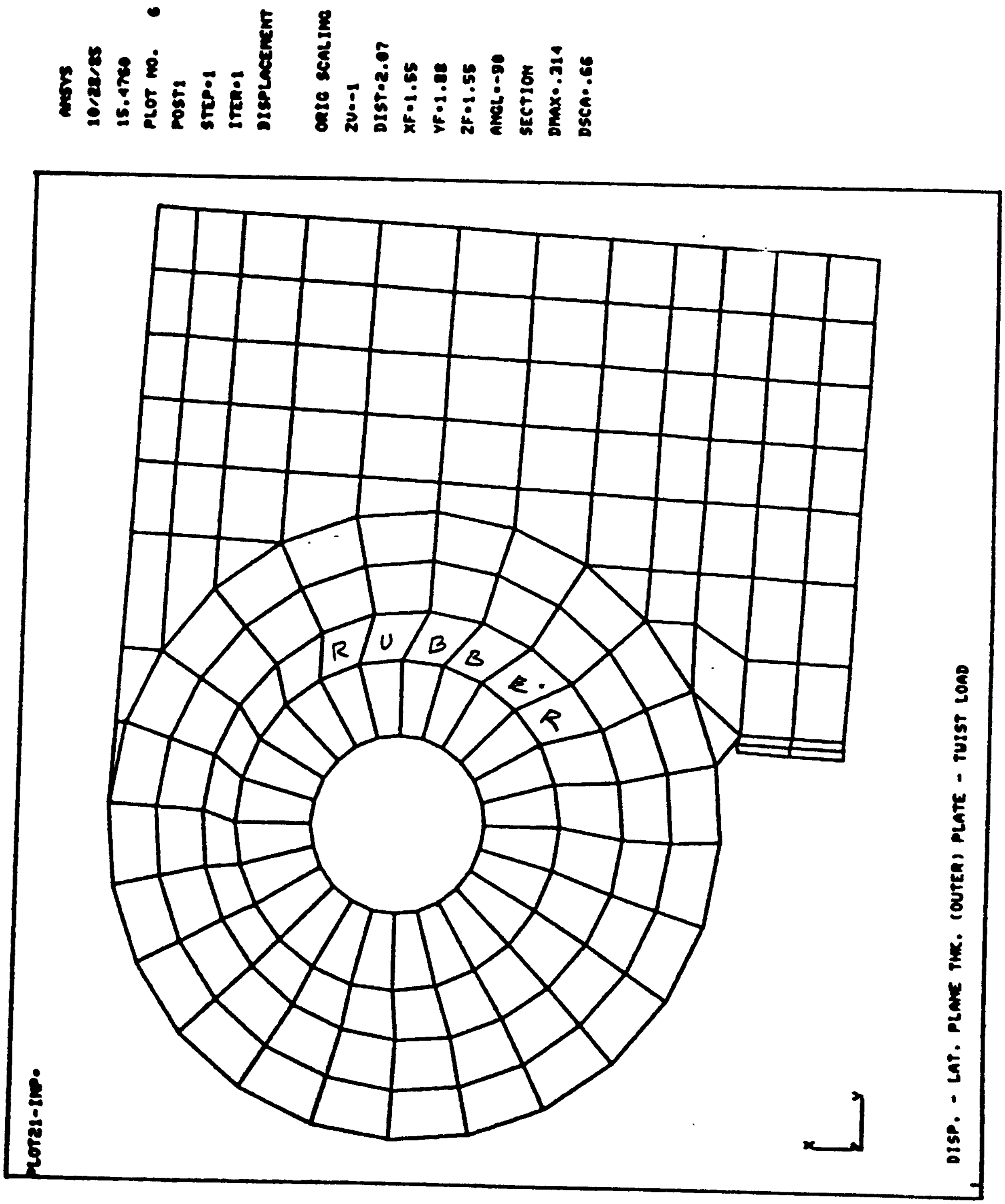


Figure 5-41 - Displacements, Plane 3, Twisting Load, Case 3

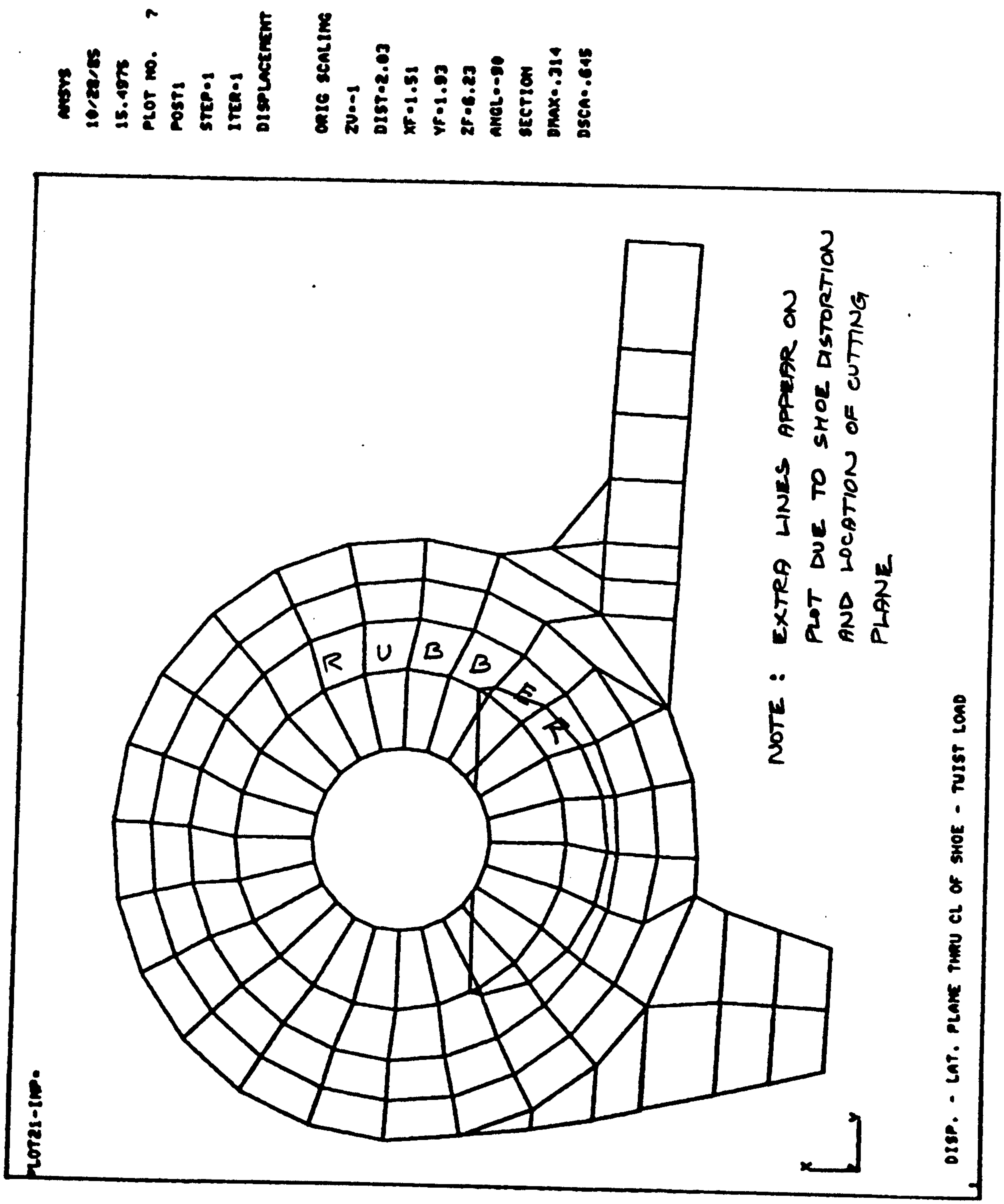


Figure 5-42 - Displacements, Plane 4, Twisting Load, Case 3

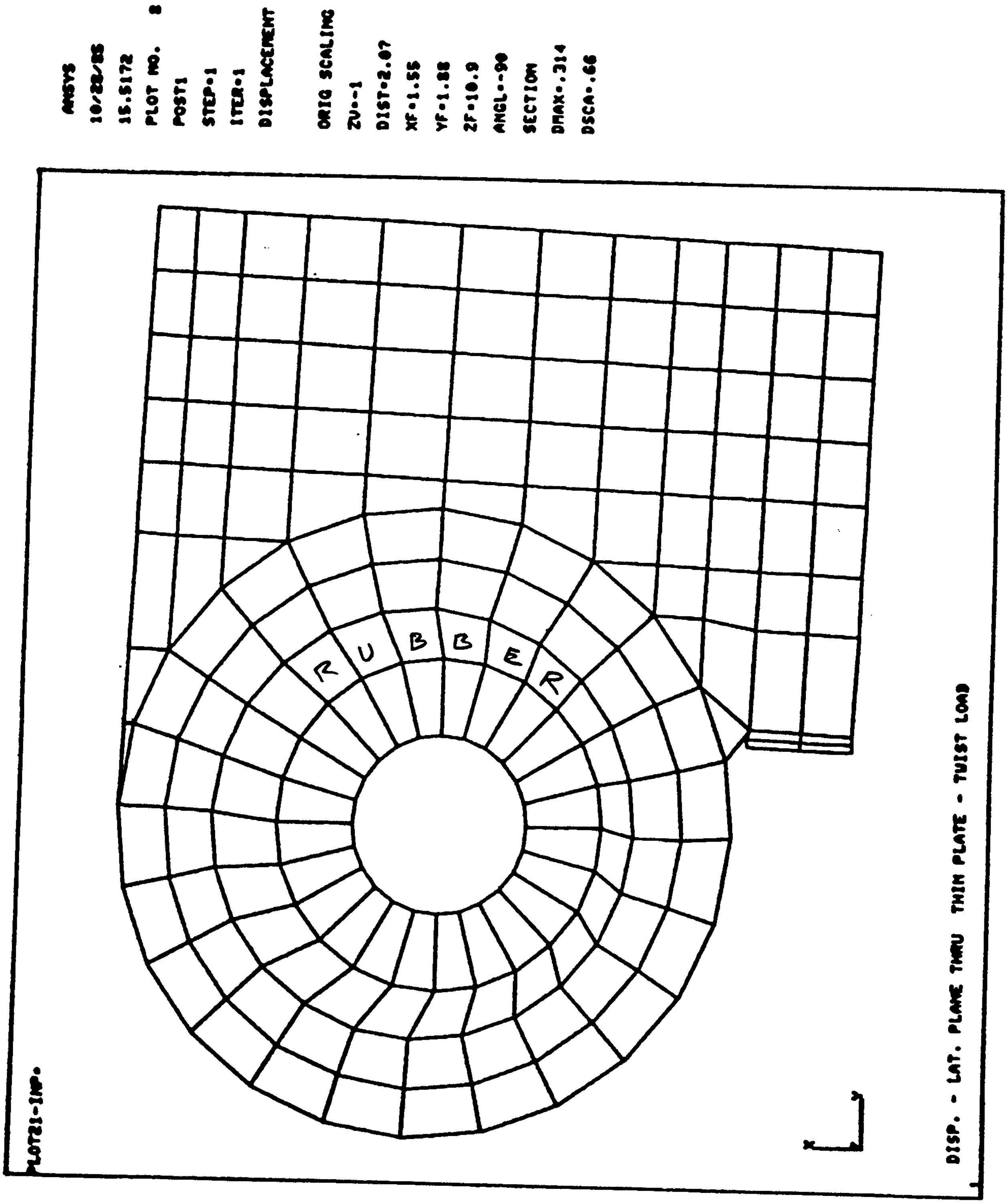


Figure 5-43 - Displacements, Plane 5, Twisting Load, Case 3

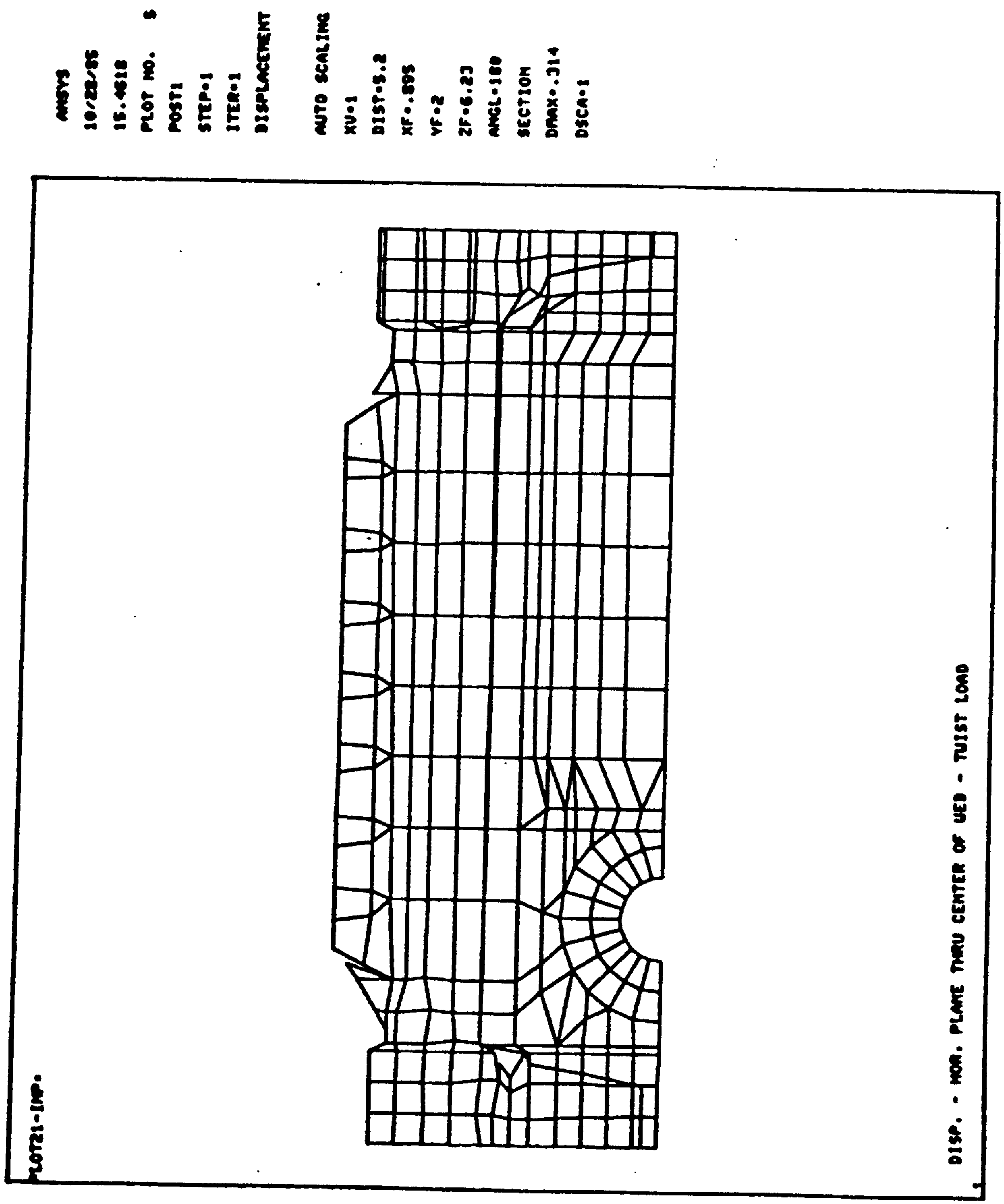


Figure 5-44 - Displacements, Plane 6, Twisting Load, Case 3

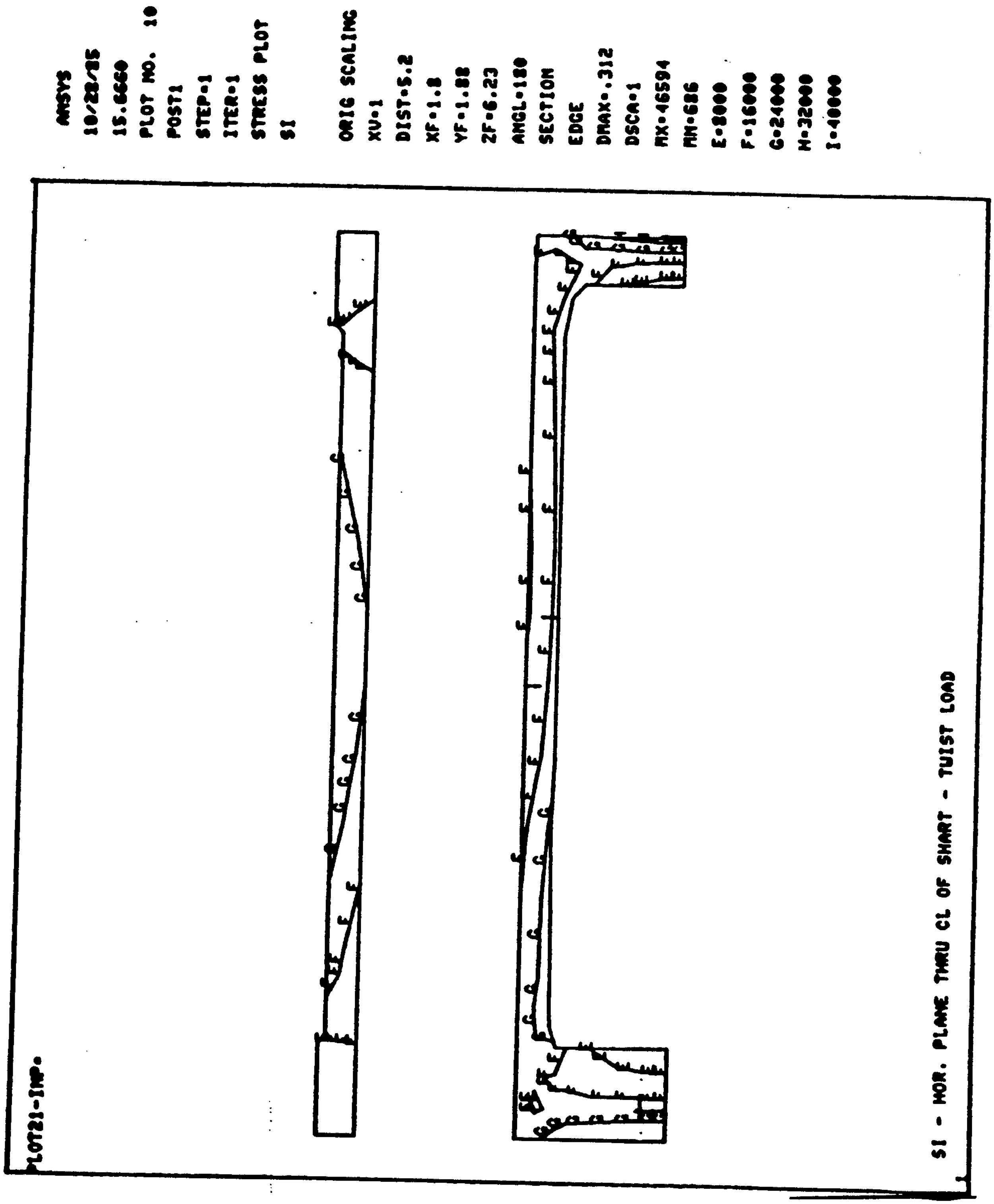


Figure 5-45 - Stress Intensity, Plane 1, Twisting Load, Case 3

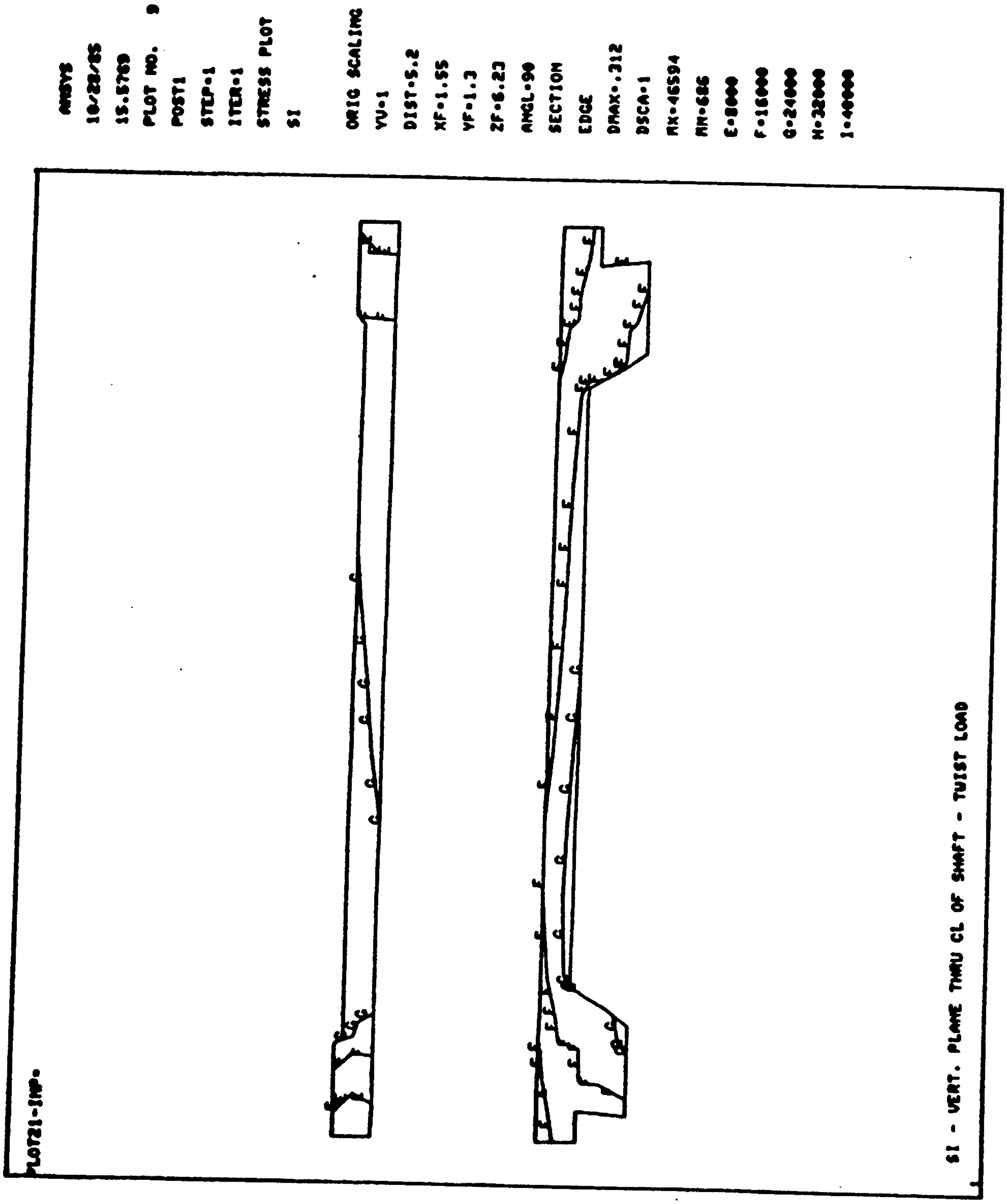


Figure 5-46 - Stress Intensity, Plane 2, Twisting Load, Case 3

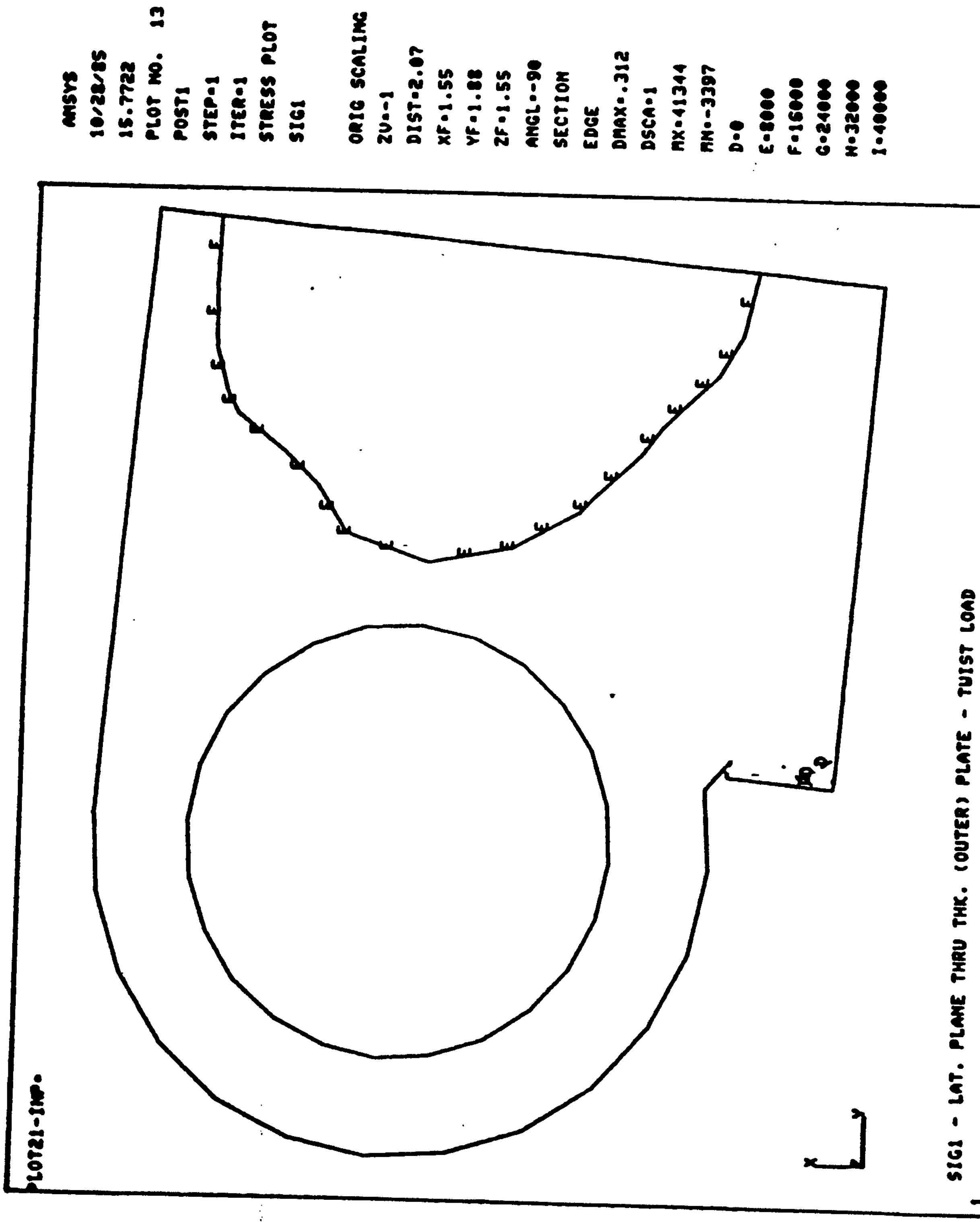


Figure 5-47 - SIG1 Principal Stress, Plane 3, Twisting Load, Case 3

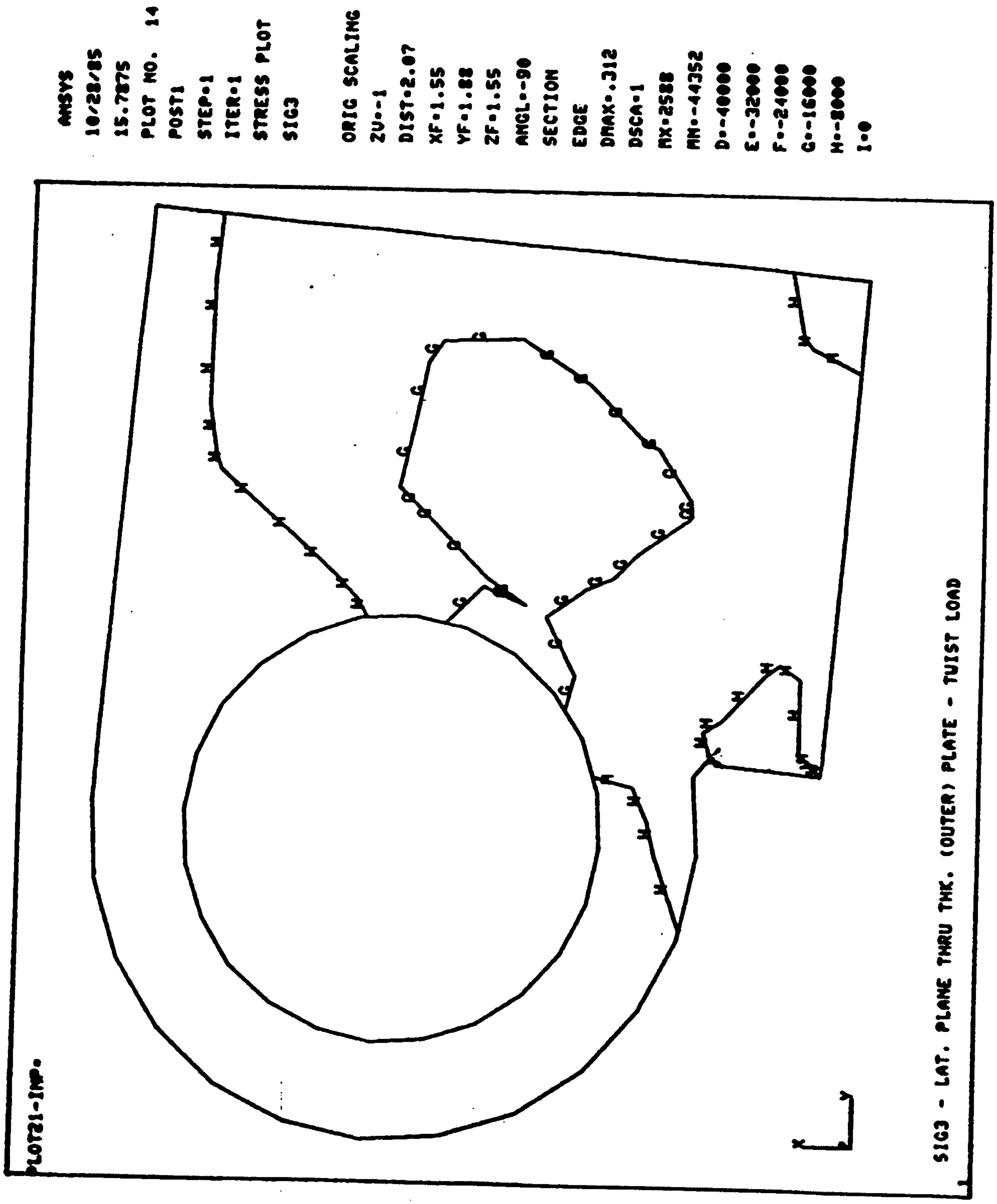


Figure 5-48 - SIG3 Principal Stress, Plane 3, Twisting Load, Case 3

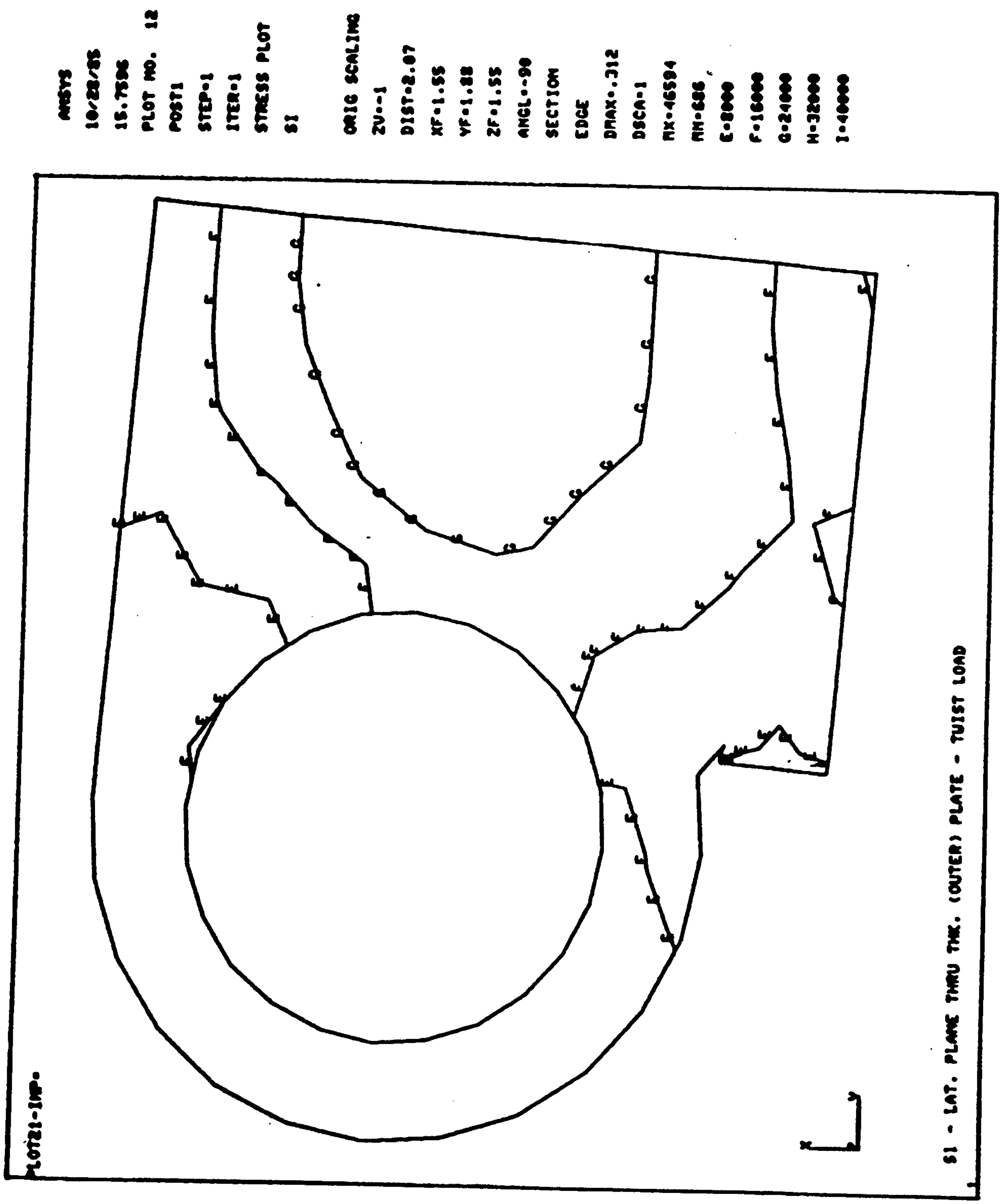


Figure 5-49 - Stress Intensity, Plane 3, Twisting Load, Case 3

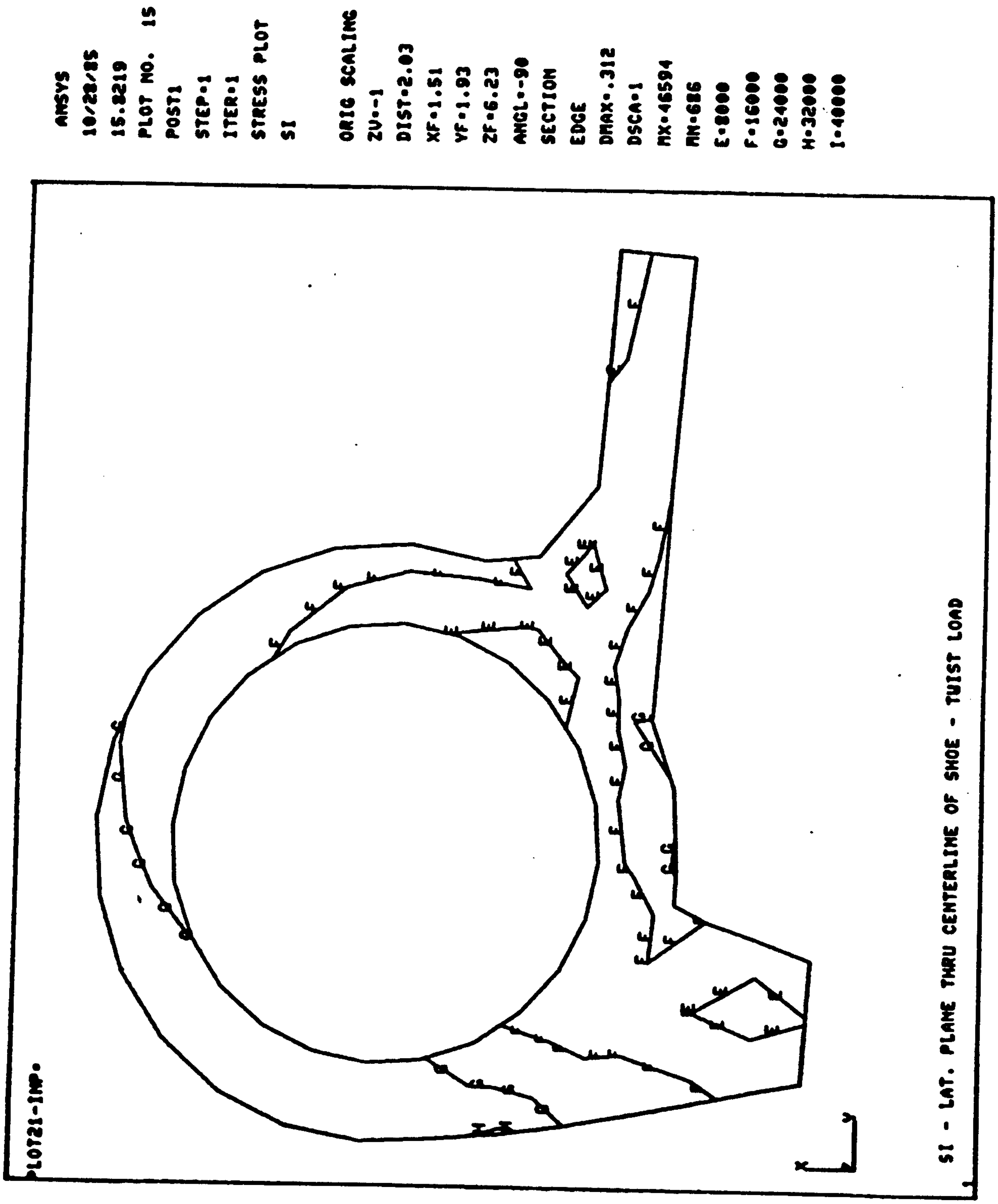


Figure 5-50 - Stress Intensity, Plane 4, Twisting Load, Case 3

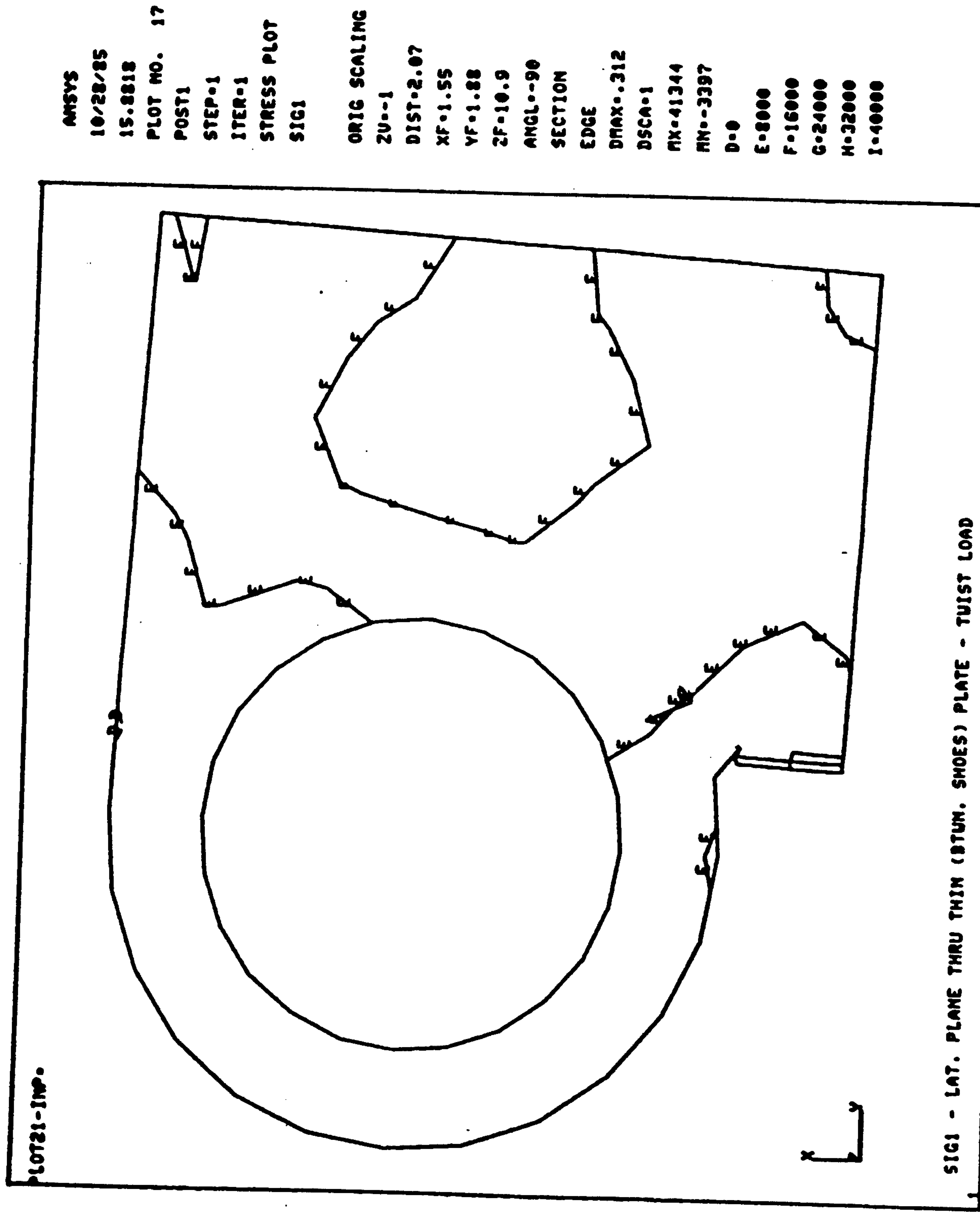


Figure 5-51 - SIG1 Principal Stress, Plane 5, Twisting Load, Case 3

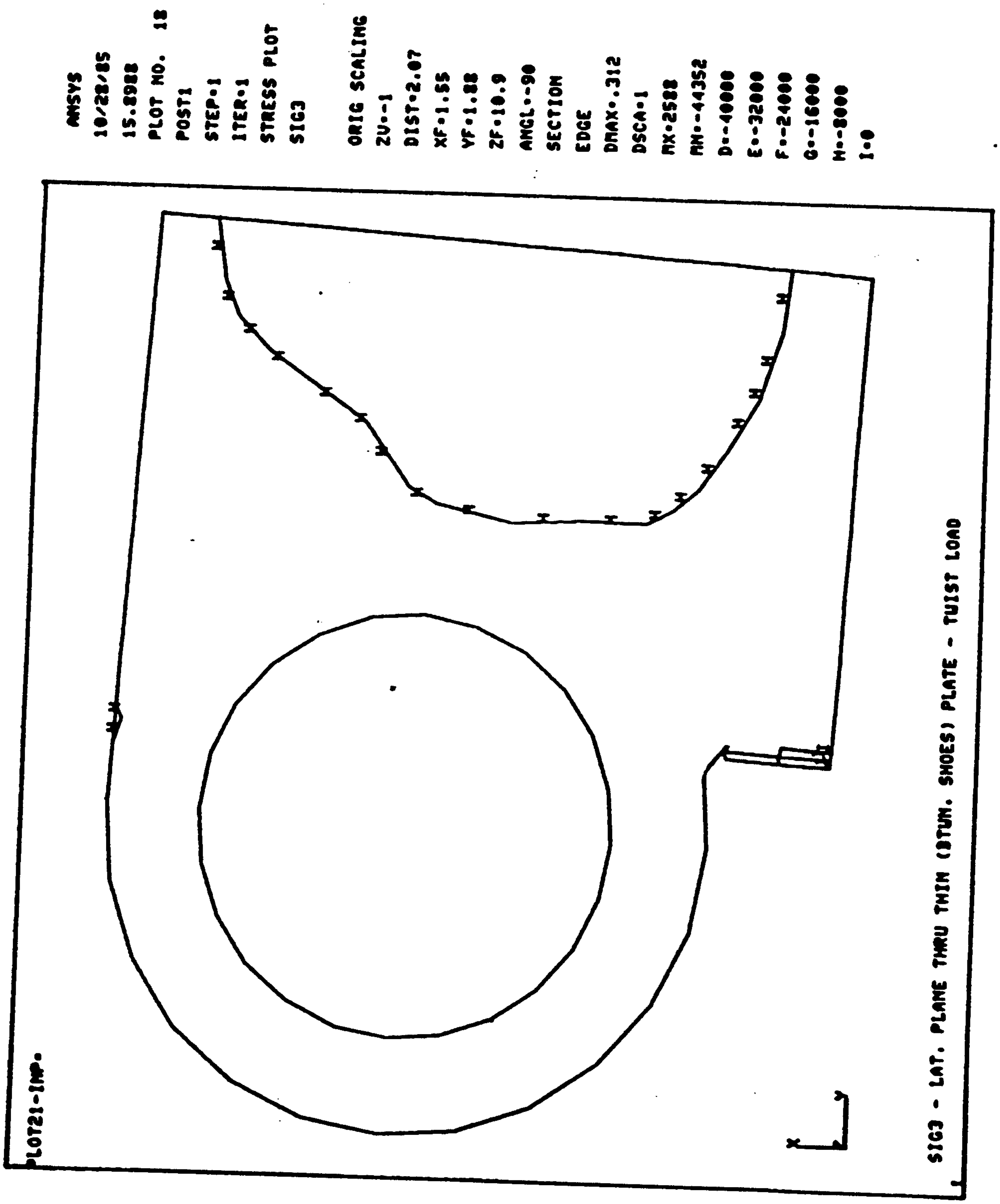


Figure 5-52 - SIG3 Principal Stress, Plane 5, Twisting Load, Case 3

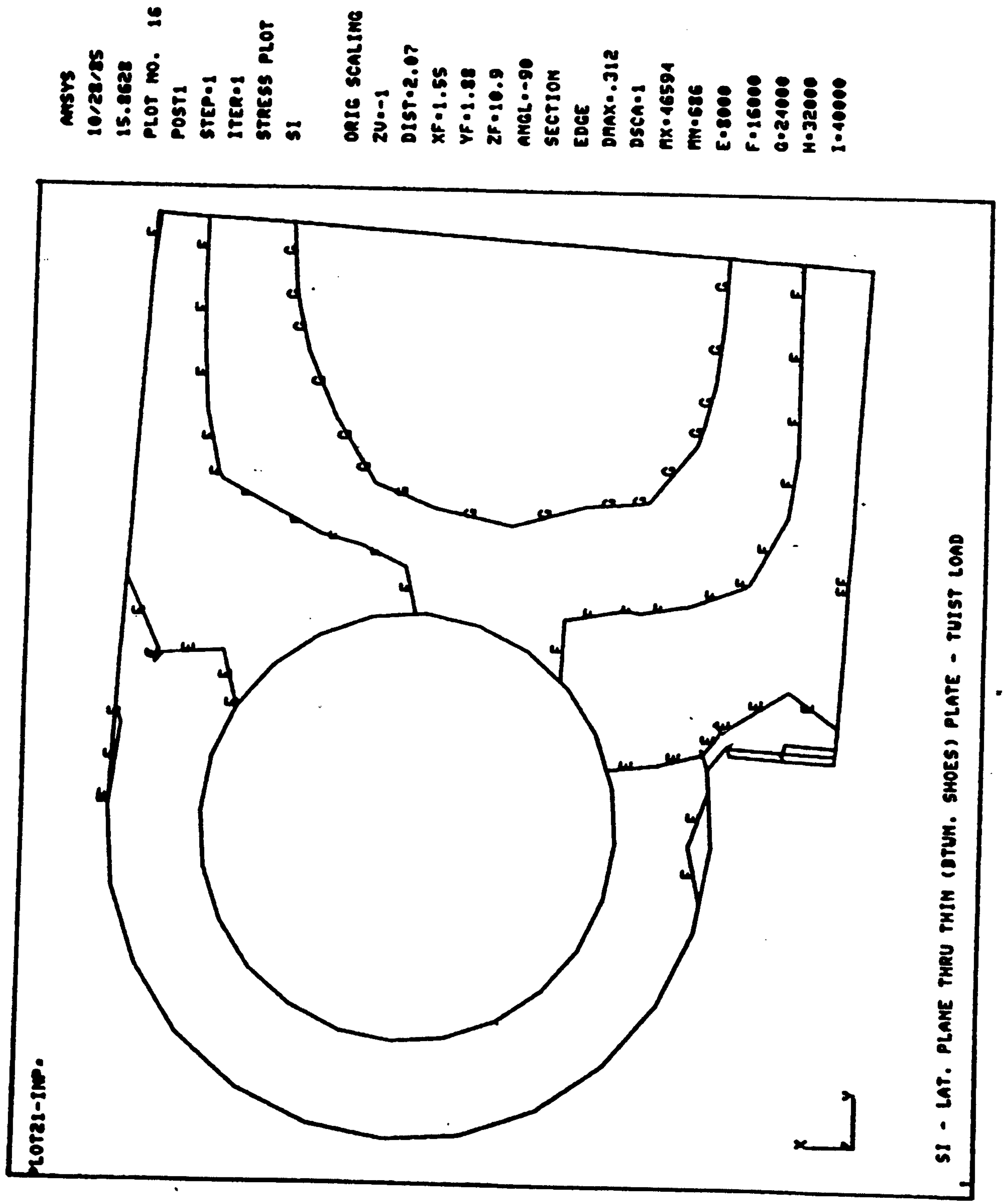


Figure 5-53 - Stress Intensity, Plane 5, Twisting Load, Case 3

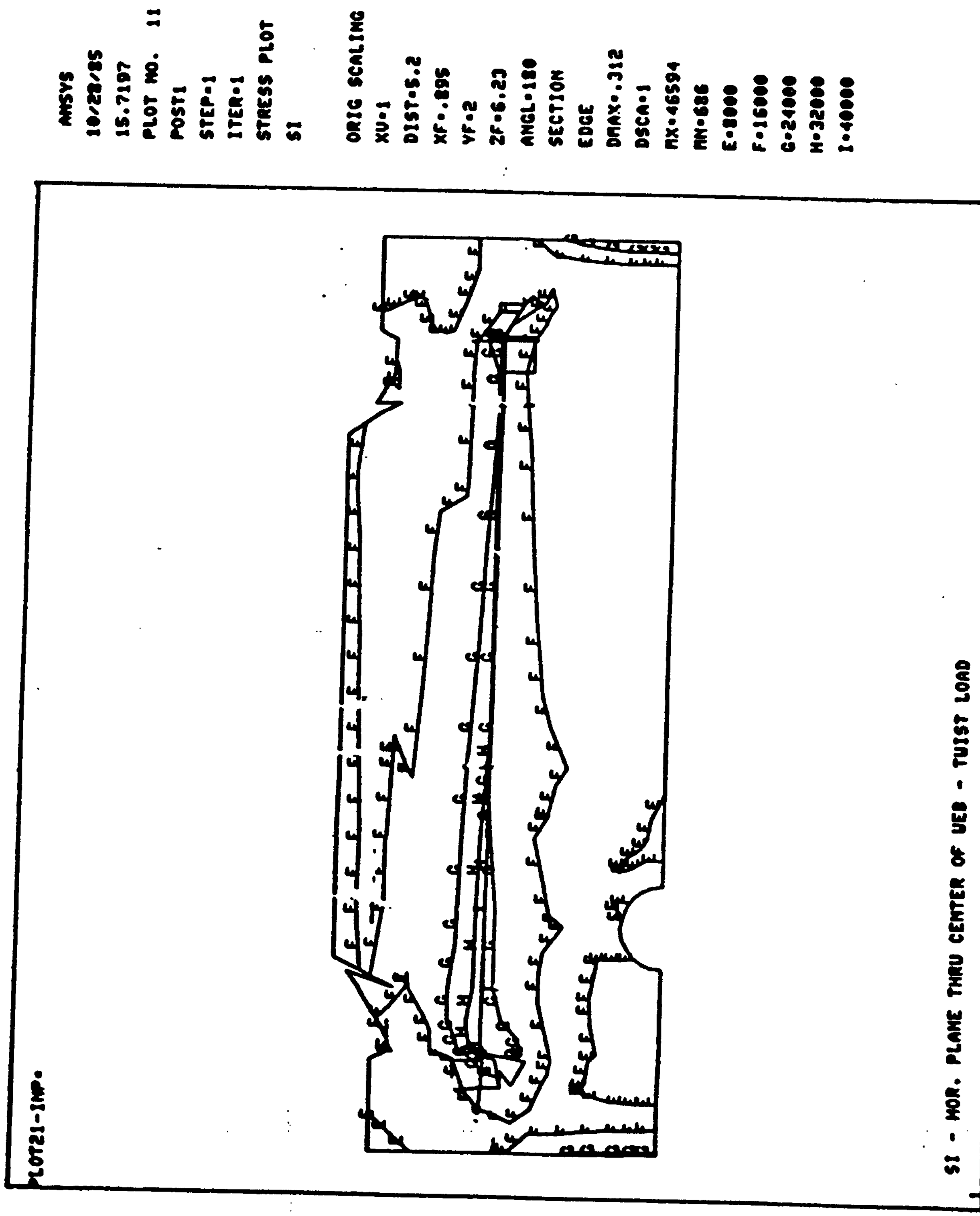


Figure 5-54 - Stress Intensity, Plane 6, Twisting Load, Case 3

6.0 LOG OF COMPUTER FILES ON ALCOA'S DEC VAX 11/785

FILENAME	DIRECTORY	DESCRIPTION
SHOEGEOM.DAT	[KAHRS2.DEAC]	ANSYS PREP7 file that generates nodes and elements of 3-D model.
SHOESF.DAT	[KAHRS2.DEAC]	ANSYS PREP7 file that contains boundary conditions (B.C.'s) and loadings.
SHOETENS5.DAT	[KAHRS2.DEAC]	ANSYS PREP7 file that contains B.C.'s and loadings for the pure tensile load case 1.5.
SHTENS512.OUT	[KAHRS2]	ANSYS binary FILE12 which contains all data for post-processing of the pure tensile load case 1.5.
SHOEBEND.DAT	[KAHRS2.DEAC]	ANSYS PREP7 file that contains B.C.'s and loadings for the out-of-plane load.
SHBEND12.OUT	[KAHRS2]	ANSYS binary FILE12 which contains all data for post-processing of the out-of-plane load.
SHOETWIST.DAT	[KAHRS2.DEAC]	ANSYS PREP7 file that contains B.C.'s and loadings for the twisting-couple load.
SHTWIST12.OUT	[KAHRS2]	ANSYS binary FILE12 which contains all data for post-processing of the twisting-couple load.
POST.COM	[KAHRS2]	ANSYS POST1 file that generates the post-processed stress tables and plots.
AEXEC.COM	[KAHRS2]	VAX command file to execute a job on the FPS.
ANS27.COM	[KAHRS2]	VAX command file to generate a FILE27 for use on the FPS.
INT.COM	[KAHRS2]	VAX command file to "wake up" ANSYS interactively.

APPENDIX A

Scope of Work
Defined for Project

Revised August 27, 1985

PROJECT: Stress analysis of tank track shoe by Finite Element Method

WORK SCOPE: Create a 3 dimensional finite element model of the track shoe represented by the attached drawing and pictures. An actual part will be shipped to Design Engineering Analysis Corporation, DEAC, to aid in the creation of the model.

DEAC shall develop a 1/2 symmetry model of the track shoe using ANSYS STIFF 45 isoparametric solid elements. The model shall include the steel pin and rubber bushing in order to develop the proper loading on the shoe, particularly in the binocular section of the shoe. There shall be approximately 3000 elements in the quadrant, with 1800 elements in the shoe forging and 1200 elements in the pin and bushing.

DEAC shall then use the 3-D model to analyze various loading conditions on the shoe. The tensile and side loads will be evaluated with the quadrant model by appling the proper boundary conditions to the planes of symmetry. The specific set of load cases to be analyzed are to be as follows:

1. Pure tension
2. Out-of-plane bending
3. Twisting

These load cases shall demonstrate part performance at the given loads. The results of the three load cases shall be reviewed, plotted separately and combined within ANSYS POST1. Other ANSYS POST1 processing shall include displacements, stress contour plots and a summary of maximum stresses.

The model shall be created using ANSYS PREP7 on a DEC VAX 11/785 located at the Alcoa Technical Center near Pittsburgh, Pa. DEAC is to supply their own terminal devices which must be compatible with 1200 baud asynchronous dial up modem devices. A Floating Point Systems FPS-164 is networked to the VAX and is available for the analysis run.

DEAC is responsible for successfully completing an analysis run for one set of load cases as described above . In the event of a numerical instability caused by modeling the rubber bushing with solids, DEAC shall replace the bushing elements with STIFF 40 combination element (2 parallel springs with a gap element) and obtain a converged solution. This work if necessary, shall be done at NO additional charge to ALCOA.

DEAC shall provide three copies of the final report. The report shall include applicable command file listings and plots. Prior to completion of the final report, a rough draft shall be submitted for review. Weekly verbal updates to ALCOA engineers will be expected.

TIMING: The project shall be complete by October 4,1985.

APPENDIX B

Development of Rubber Properties for Bushing Material

The bushing material between the steel pin and aluminum forging is natural rubber. The following material specifications and fabrication procedures were provided by Dan Carbaugh of Alcoa by telephone on September 3, 1984:

Bushing Material:	Natural Rubber (NR) Ultimate tensile strength = 3000 psi Shore A durometer = 65-70
Fabrication:	Rubber rings or doughnuts are molded and bonded to steel pins at intervals. Rubber doughnuts are compressed 35% from free state when pressed into track shoe binocular. Rubber expands axially to close up gaps between the doughnuts.

Rubber is an elastomeric or viscoelastic material which exhibits high elongation and high speed of retraction. The idealized behavior most nearly approximating that of rubberlike materials is known as linear viscoelastic behavior. Rubber does not follow Hooke's law and can be characterized by a non-linear elastic behavior which becomes stiffer with increasing strain, i.e., the tangent modulus increases with increasing load. Rubber also exhibits some time-dependent permanent viscous or creep deformation.

Probably the most important property of rubber for design purposes is the modulus of elasticity which is difficult to specify since the material is non-linear. Additionally, the stress-strain curves for rubber in tension, compression, and shear are all different. For these reasons, it is common to specify the durometer hardness of rubber materials. The rubber hardness is not important

of itself, but it is merely an approximate and convenient measurement which is related to the modulus of elasticity and is independent of a specimen shape factor.

Since a compressive stress-strain curve for the natural rubber is not available, a compressive stress-strain curve for a similar rubber was used to determine an effective modulus of elasticity for our study. Figure B-1 shows a compressive stress-strain curve for Nitrile Butyl Rubber (NBR) with a 90 durometer reading. Since the durometer hardness readings of both rubbers are similar (70 vs. 90), the NBR stress-strain curve was used for analysis purposes. The rubber comparisons shown in Tables B-1 and B-2 also suggest similarities between NR and NBR rubber.

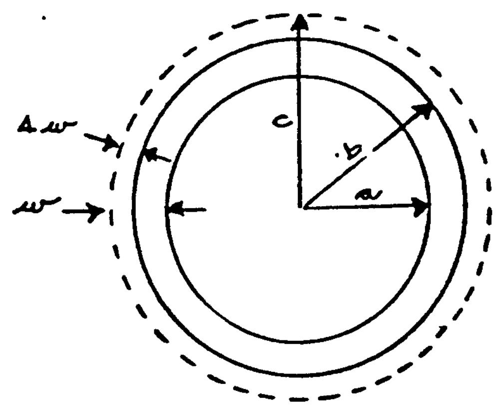
Since rubber is basically a nonlinear elastic material, a plastic-type iterative solution is required to follow the rubber stress-strain curve. A nonlinear analysis is not economically feasible for large 3-D models as in our case. Additionally, the rubber is only incidental to our problem in that it is required for proper load transfer from the pin to the forging. Our approach will be to select an effective Young's modulus from the rubber stress-strain curve that will approximate the actual rubber stiffness of the assembly.

Since the rubber is compressed 35% when press-fit into the binocular, determine the free height of the doughnut.

Let $a = \frac{1.375''}{2} = .6875'' =$ pin outside radius

$b = \frac{1.781''}{2} = .8905'' =$ binocular inside radius

c = free radius of rubber doughnut



$$\frac{\Delta\omega}{\omega} = \frac{c-b}{c-a} = .35$$

$$c = \frac{b-.35a}{.65} = 1.000''$$

Therefore, the rubber is compressed or preloaded to $(c-b) = 1.000'' - .8905'' = .1095''$ on a radius. The final annular compressed thickness of the rubber is $(b-a) = .8905'' - .6875'' = .203''$ which corresponds to a 35% preload.

Using the stress-strain curve in Figure B-1, the tangent modulus at 35% strain is equal to E_3. Therefore, assume an elastic modulus of E = 20,000 psi as a first approximation for our analysis. Rubber is essentially an incompressible substance that deflects by changing shape rather than changing volume.

Therefore, Poisson's ratio approaches 1/2, and for analysis purposes we will use a value of .49.

This assumption will be checked out using a simplified ANSYS STIF42 plane model of the pin and rubber. The plane model will have a unit depth. Therefore, the model will use an equivalent pin height to maintain the proper bending stiffness.

The moment of inertia of the steel pin is:

$$I = \frac{\pi}{64}(D_o^4 - D_i^4) = \frac{\pi}{64}(1.375^4 - .7375^4) = .1609 \text{ in}^4$$

For an equivalent rectangular beam of unit depth:

$$d^3 = \frac{12I}{b} = \frac{12(.1609)}{1} = 1.9308$$

$$d = 1.2452''$$

The ANSYS 2-D model of the pin and rubber is shown in Figure B-2. The model node numbers are shown in Figure B-3, and the boundary conditions are shown in Figure B-4. This model assumes the aluminum is infinitely rigid for these studies. A load of 18,000 lbs. was applied to this half-symmetry model which corresponds to the load deflection test performed by Goodyear.

Figure B-5 shows the load-deflection curve provided by Goodyear. A maximum load of 36,000 lbs. was applied to the shoe and the resulting deflection was

.098". These values will be used as a basis to select an effective elastic modulus and qualify the model.

Two limiting cases (plane strain and plane stress) were run with the 2-D model described in Figure B-2. The plane strain case tends to over-estimate the rubber stiffness because the strain in the Z-direction (into the plane of page) is $\varepsilon_z = 0$. Since rubber is incompressible, the only deformation it can take is out the ends. The plane stress case tends to under-estimate the rubber stiffness because the stress in the Z-direction is $\sigma_z = 0$. This allows deformation in the Z-direction and out the ends. The actual 3-D case is probably between these limiting cases.

The plane strain deformation plots are shown in Figures B-6 and B-7. The displacement scale (DSCALE = 4.14) is exaggerated in Figure B-6 and is equal to 1.0 in Figure B-7. Figures B-8 and B-9 show the displacement plots for the plane stress case. Table B-3 shows the ANSYS PREP7 input listing for the plane stress case. Tables B-4 and B-5 list the complete displacement solution for both cases.

The maximum displacements for the two limiting cases are:

Plane strain, Displacement = .04590"
Plane stress, Displacement = .11019"

The test results show that the measured displacement for 36,000 lbs. is .098"

which lies between the calculated values. The average displacement of the two calculated values is .078" which is in the same ballpark as the test results. Noting that the 2-D model did not include the aluminum flexibility, the assumed rubber properties of $E = 20{,}000$ psi and $\nu = .49$ are considered satisfactory for initial use in the 3-D model. These properties will be modified as the 3-D model is qualified in the calibration runs in Section 5.2.

TABLE B-1
Relative Properties of Various Rubbers

35-8 RUBBER SPRINGS

Table 35.3. Relative Properties

Poymer designation	Common name	Shore A hardness range	Max. tensile strength		Compression set	Tear resistance	Resilience		Heat resistance	Outdoor aging resistance
			lb/in.²	kg/cm²			Room temp.	High temp.		
NR.......	Natural	30-100	4,000	280	Good	Good	High	High	Fair	Fair
SBR......	SBR	40-100	3,000	210	Good	Fair	Fairly high	Fairly high	Fair	Fair
CR.......	Neoprene	40-95	3,000	210	Poor (GN) Good (W)	Good	Fairly high	Fairly high	Good	Excellent
IIR.......	Butyl	40-75	2,000	140	Fair	Good	Low	Fairly high	Good	Good
EPDM...	EPDM	45-100	2,000	140	Fair	Fair	Fairly high	Fairly high	Excellent	Excellent
NBR.....	Nitrile	20-100	2,500	176	Good	Fair	Medium	Medium	Good to excellent	Poor
PO.......	Propylene Oxide	45-80	2,000	140	Fair	Fair	Fairly high	Fairly high	Good to excellent	Excellent
--	Thiokol	20-80	1,300	91	Poor	Good	Medium	Fairly high	Fair	Excellent
Si........	Silicone	30-90	1,000	70	Excellent	Poor	Fairly high	Medium	Excellent	Excellent
CSM.....	Hypalon	45-95	2,800	197	Fair	Fair to good	Fairly high	High	Excellent	Excellent
ACM.....	Polyacrylate	40-90	1,800	127	Good	Fair to poor	Low	High	Excellent	Excellent
FPM.....	Fluororubber	60-90	3,000	210	Excellent	Fair to poor	Medium	Medium	Excellent	Excellent

* The relative ease of obtaining good adhesion to metal without employing costly metal treatments and elements.

Reference: Harris and Crede, Shock & Vibration Handbook, 2nd Edition, McGraw-Hill, 1976.

TABLE B-2
Comparison of Various Rubber Properties

4 RUBBER & ELASTOMERS

Rubber — Molded, Extruded

Type →	ASTM	NR Natural Rubber (Cis-polyisoprene)	Butadiene-Styrene (GR-S)	Synthetic (Polyisoprene)	NBR Butadiene-Acrylonitrile (Nitrile)	Chloroprene (Neoprene)	Butyl (Isobutylene-Isoprene)
PHYSICAL PROPERTIES							
Specific Gravity	D792	0.93	0.94	0.93	0.98	1.25	0.90
Ther Cond, Btu/hr/sq ft/°F/ft	C177	0.082	0.143	0.082	0.143	0.112	0.053
Coef of Ther Exp (cubical), 10^{-5} per °F	D696	37	37	—	39	34	32
Electrical Insulation		Good	Good	Good	Fair	Fair	Good
Flame Resistance		Poor	Poor	Poor	Poor	Good	Poor
Min Rec Svc Temp, F		−60	−60	-60	−40	−40	-50
Max Rec Svc Temp, F		180	180	180	300	240	300
MECHANICAL PROPERTIES							
Ten Str, psi							
Pure Gum	D412	2500–3500	200–300	2500-3500	500–900	3000–4000	2500–3000
Black	D412	3500–4500	2500–3500	3500-4500	3000–4500	3000–4000	2500–3000
Elongation, %							
Pure Gum	D412	750–850	400–600	—	300-700	800–900	750–950
Black	D412	550–650	500–600	300–700	300-650	500–600	650–850
Hardness (durometer)		A30–A90	A40–A90	A40–A80	A40–A95	A20-A95	A40–A90
Rebound							
Cold		Excellent	Good	Excellent	Good	Very good	Bad
Hot		Excellent	Good	Excellent	Good	Very good	Very good
Tear Resistance		Excellent	Fair	Excellent	Good	Fair to good	Good
Abrasion Resistance		Excellent	Good to excellent	Excellent	Good to excellent	Good	Good to excellent
CHEMICAL RESISTANCE							
Sunlight Aging		Poor	Poor	Fair	Poor	Very good	Very good
Oxidation		Good	Good	Excellent	Good	Excellent	Excellent
Heat Aging		Good	Very good	Good	Excellent	Excellent	Excellent
Solvents							
Aliphatic Hydrocarbons		Poor	Poor	Poor	Excellent	Good	Poor
Aromatic Hydrocarbons		Poor	Poor	Poor	Good	Fair	Poor
Oxygenated, Alcohols		Good	Good	Good	Good	Very good	Very good
Oil, Gasoline		Poor	Poor	Poor	Excellent	Good	Poor
Animal, Vegetable Oils		Poor to good	Poor to good	—	Excellent	Excellent	Excellent
Acids							
Dilute		Fair to good	Fair to good	Fair to good	Good	Excellent	Excellent
Concentrated		Fair to good	Fair to good	Fair to good	Good	Good	Excellent
Permeability to Gases		Low	Low	Low	Very low	Low	Very low
Water Swell Resistance		Fair	Excellent	Excellent	Excellent	Fair to excellent	Excellent
USES		Pneumatic tires and tubes; power transmission belts and conveyor belts; gaskets; mountings; hose; chemical tank linings; printing press platens; sound or shock absorption; seals against air, moisture, sound and dirt		Same as natural rubber	Carburetor diaphragms, self-sealing fuel tanks, aircraft hose, gaskets, gasoline and oil hose, cables, machinery mountings, printing rolls	Wire and cable, belts, hose, extruded goods, coatings, molded and sheet goods, adhesives, automotive gaskets and seals, petroleum and chemical tank linings	Truck and automobile tire inner tubes, curing bags for tire vulcanization and molding, steam hose and diaphragms, flexible electrical insulation, shock, vibration absorption

Reference: 1972 Materials Selector, Materials Engineering, Reinhold Publishing Corporation, Stamford, CT, 1971.

TABLE B-3

ANSYS Input Listing for

2-D Model Plane Stress Case

```
/PREP7
/TITLE, SAMPLE PROBLEM TO TEST RUBBER PROP, PLANE STRESS
ET,1,42,,,3
ET,2,42,,,3
R,1,1
N,1,0,.8256
N,2,0,.6226
N,3,0,0
N,4,0,-.6226
N,5,0,-.8256
NGEN,10,5,1,5,,.5
NGEN,2,50,1,5,,4.73
NGEN,2,55,2,4,,5.0
NGEN,3,5,57,59,,.5
MAT,2
TYPE,2
REAL,1
E,6,1,2,7
MAT,1
TYPE,1
E,7,2,3,8
RP2,1,1,1,1
MAT,2
TYPE,2
E,5,10,9,4
EGEN,10,5,-4
EGEN,2,50,2,3
EGEN,3,5,-2
EPLOT
NPLOT,1
EX,1,30E6
ALPX,1,0
NUXY,1,.3
EX,2,.02E6
ALPX,2,0
NUXY,2,.49
CP,1,UY,67,68,69
TIME,0
ITER,1,1,1
KRF,2
KTEMP,0
D,1,UX,0,0,5,1
D,1,UY,0,0,51,5
D,5,UY,0,0,55,5
F,67,FY,18000
GLINE,1
TDBC,1
FBC,1
EPLOT
LWRITE
AFWRITE,,1
FINISH
/INPUT,27
FINISH
/POST1
SET,1,1
/NOERASE
PLDISP
/ERASE
PLDISP
/VIEW,,1,1,1
PLDISP
FINISH
```

TABLE B-4
Displacement Solution for
2-D Model Plane Strain Case

```
      ANSYS - ENGINEERING ANALYSIS SYSTEM  REVISION 4.1      C     SASI 8000        JAN 1,1983
 SWANSON ANALYSIS SYSTEMS, INC.        HOUSTON, PENNSYLVANIA 15342   PHONE (412)746-3304  TWX 510-690-8655

SAMPLE PROBLEM TO TEST RUBBER PROP, PLANE STRAIN                          17.3078  10/ 4/85 CP=     16.936

***** DISPLACEMENT SOLUTION *****  TIME =   .00000E+00  LOAD STEP=   1  ITERATION=     1  CUM. ITER.=    1
```

NODE	UX	UY
1	.000000E+00	.000000E+00
2	.000000E+00	-.299159E-02
3	.000000E+00	-.306050E-02
4	.000000E+00	-.299159E-02
5	.000000E+00	.000000E+00
6	-.201856E-02	.000000E+00
7	-.153678E-03	-.299765E-02
8	-.140946E-17	-.308144E-02
9	.153678E-03	-.299765E-02
10	.201856E-02	.000000E+00
11	-.479981E-02	.000000E+00
12	-.425361E-03	-.296392E-02
13	-.260209E-17	-.309040E-02
14	.425361E-03	-.296392E-02
15	.479981E-02	.000000E+00
16	-.891456E-02	.000000E+00
17	-.921065E-03	-.273782E-02
18	-.395734E-17	-.292868E-02
19	.921065E-03	-.273782E-02
20	.891456E-02	.000000E+00
21	-.144948E-01	.000000E+00
22	-.172063E-02	-.207667E-02
23	-.527871E-17	-.234295E-02
24	.172063E-02	-.207667E-02
25	.144948E-01	.000000E+00
26	-.208606E-01	.000000E+00
27	-.286022E-02	-.669650E-03
28	-.672205E-17	-.100701E-02
29	.286022E-02	-.669650E-03
30	.208606E-01	.000000E+00
31	-.259052E-01	.000000E+00
32	-.431327E-02	.182433E-02
33	-.710152E-17	.143879E-02
34	.431327E-02	.182433E-02
35	.259052E-01	.000000E+00
36	-.250143E-01	.000000E+00
37	-.597625E-02	.571848E-02
38	-.748099E-17	.532427E-02
39	.597625E-02	.571848E-02
40	.250143E-01	.000000E+00
41	-.904373E-02	.000000E+00
42	-.767556E-02	.112212E-01
43	-.775205E-17	.108590E-01
44	.767556E-02	.112212E-01
45	.904373E-02	.000000E+00
46	.396808E-01	.000000E+00

NODE	UX	UY
47	-.922815E-02	.183527E-01
48	-.954098E-17	.180209E-01
49	.922815E-02	.183527E-01
50	-.396808E-01	.000000E+00
51	.797656E-01	.000000E+00
52	-.985976E-02	.221293E-01
53	-.997466E-17	.218125E-01
54	.985976E-02	.221293E-01
56	-.797656E-01	.000000E+00
57	-.104999E-01	.268603E-01
58	-.954098E-17	.265874E-01
59	.104999E-01	.268603E-01
62	-.112904E-01	.361716E-01
63	-.867362E-17	.360284E-01
64	.112904E-01	.361716E-01
67	-.115552E-01	.458999E-01
68	-.101915E-16	.458999E-01
69	.115552E-01	.458999E-01

MAXIMUMS		
NODE	51	67
VALUE	.797656E-01	.458999E-01

TABLE B-5
Displacement Solution for 2-D Model Plane Stress Case

```
            ANSYS - ENGINEERING ANALYSIS SYSTEM  REVISION 4.1      C      SASI 8000          JAN 1,1983
     SWANSON ANALYSIS SYSTEMS, INC.        HOUSTON, PENNSYLVANIA 15342   PHONE (412)746-3304  TWX 510-690-8655

SAMPLE PROBLEM TO TEST RUBBER PROP, PLANE STRESS                                  17.5225  10/ 4/85 CP=      16.813

***** DISPLACEMENT SOLUTION *****  TIME =   .00000E+00  LOAD STEP=   1  ITERATION=    1  CUM. ITER.=    1
```

NODE	UX	UY
1	.000000E+00	.000000E+00
2	.000000E+00	-.102051E-01
3	.000000E+00	-.105878E-01
4	.000000E+00	-.102051E-01
5	.000000E+00	.000000E+00
6	-.293321E-02	.000000E+00
7	-.199232E-02	-.942504E-02
8	-.542101E-17	-.981025E-02
9	.199232E-02	-.942504E-02
10	.293321E-02	.000000E+00
11	-.591938E-02	.000000E+00
12	-.401979E-02	-.706761E-02
13	-.112215E-16	-.745947E-02
14	.401979E-02	-.706761E-02
15	.591938E-02	.000000E+00
16	-.900163E-02	.000000E+00
17	-.611089E-02	-.308334E-02
18	-.166967E-16	-.348413E-02
19	.611089E-02	-.308334E-02
20	.900163E-02	.000000E+00
21	-.122033E-01	.000000E+00
22	-.828067E-02	.260142E-02
23	-.230393E-16	.219265E-02
24	.828067E-02	.260142E-02
25	.122033E-01	.000000E+00
26	-.155174E-01	.000000E+00
27	-.105237E-01	.100712E-01
28	-.286229E-16	.965996E-02
29	.105237E-01	.100712E-01
30	.155174E-01	.000000E+00
31	-.188997E-01	.000000E+00
32	-.128068E-01	.194023E-01
33	-.328513E-16	.190002E-01
34	.128068E-01	.194023E-01
35	.188997E-01	.000000E+00
36	-.221881E-01	.000000E+00
37	-.150617E-01	.306382E-01
38	-.364292E-16	.302637E-01
39	.150617E-01	.306382E-01
40	.221881E-01	.000000E+00
41	-.263916E-01	.000000E+00
42	-.171761E-01	.437564E-01
43	-.416334E-16	.434394E-01
44	.171761E-01	.437564E-01
45	.263916E-01	.000000E+00
46	-.919317E-02	.000000E+00

NODE	UX	UY
47	-.190042E-01	.586476E-01
48	-.433681E-16	.583978E-01
49	.190042E-01	.586476E-01
50	.919317E-02	.000000E+00
51	.293761E-01	.000000E+00
52	-.197151E-01	.660476E-01
53	-.442354E-16	.658181E-01
54	.197151E-01	.660476E-01
55	-.293761E-01	.000000E+00
57	-.204216E-01	.750802E-01
58	-.477049E-16	.748678E-01
59	.204216E-01	.750802E-01
62	-.212916E-01	.924048E-01
63	-.494396E-16	.922953E-01
64	.212916E-01	.924048E-01
67	-.215821E-01	.110192
68	-.468375E-16	.110192
69	.215821E-01	.110192

MAXIMUMS		
NODE	55	67
VALUE	-.293761E-01	.110192

Reference: "Nonlinear Analysis of Axisymmetric Rubber Structures," by David A. Bobinger, Delco Products, Published in the ANSYS Conference Proceedings, by Swanson Analysis Systems, Inc., Houston, PA, 1983.

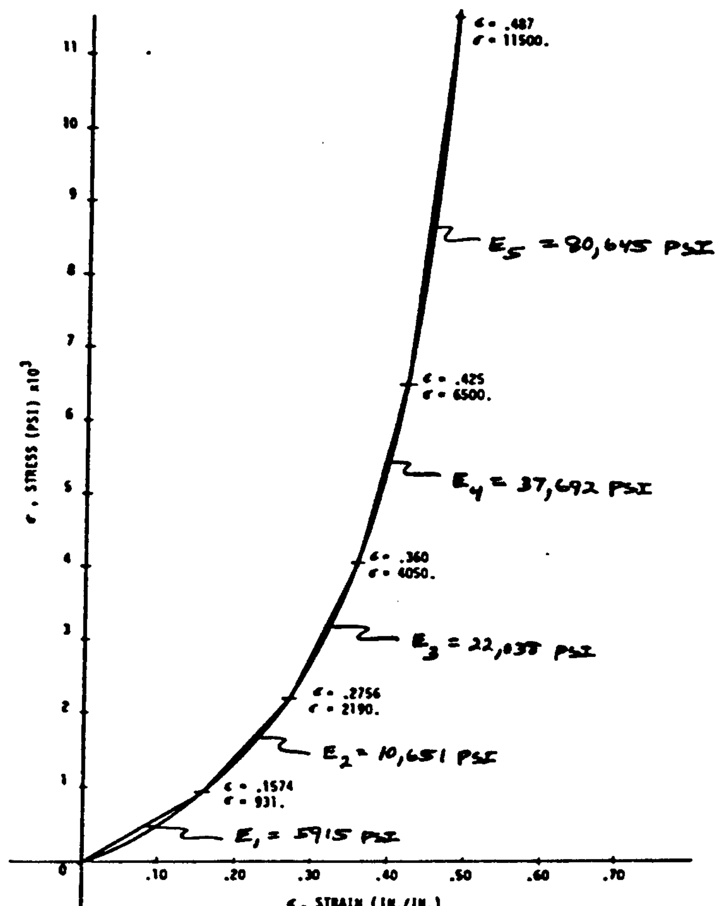


FIGURE 2.
NBR 90 DURO STRESS - STRAIN CURVE

Figure B-1 - Compressive Stress-Strain Curve for NBR Rubber with 90 Durometer

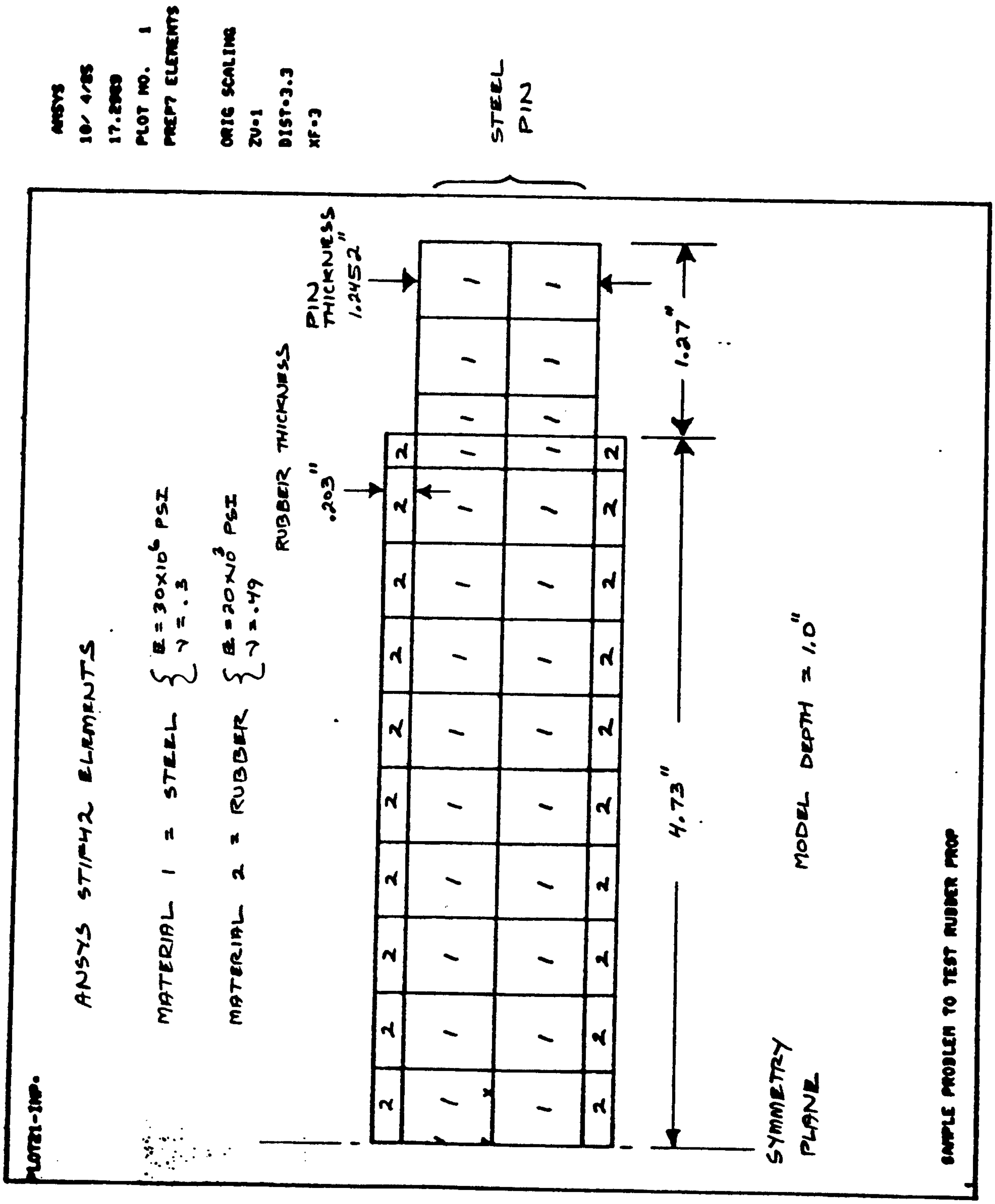


Figure B-2 - Simplified ANSYS 2-D Plane Model of Pin and Rubber

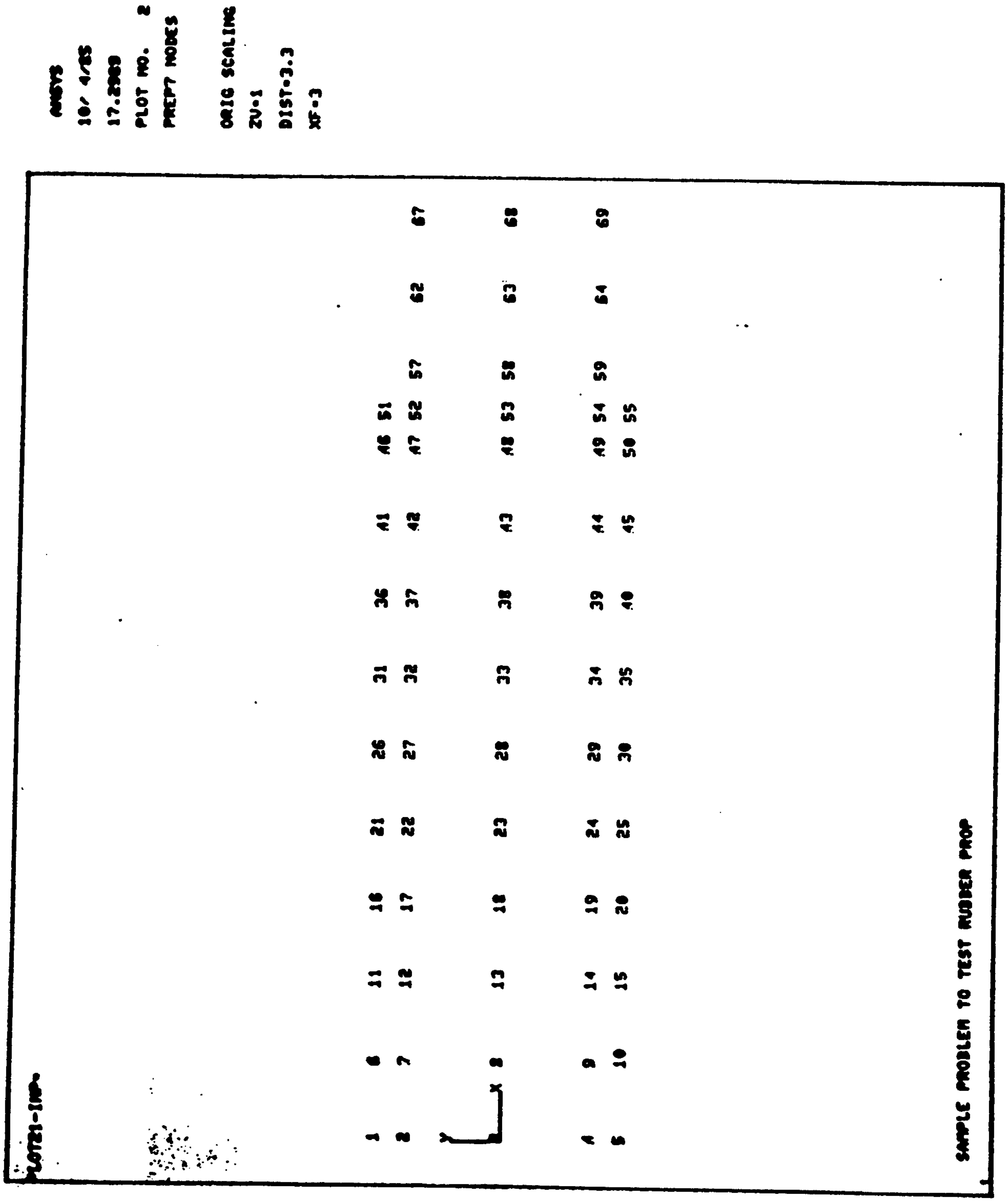


Figure B-3 - 2-D Model Nodal Point Locations

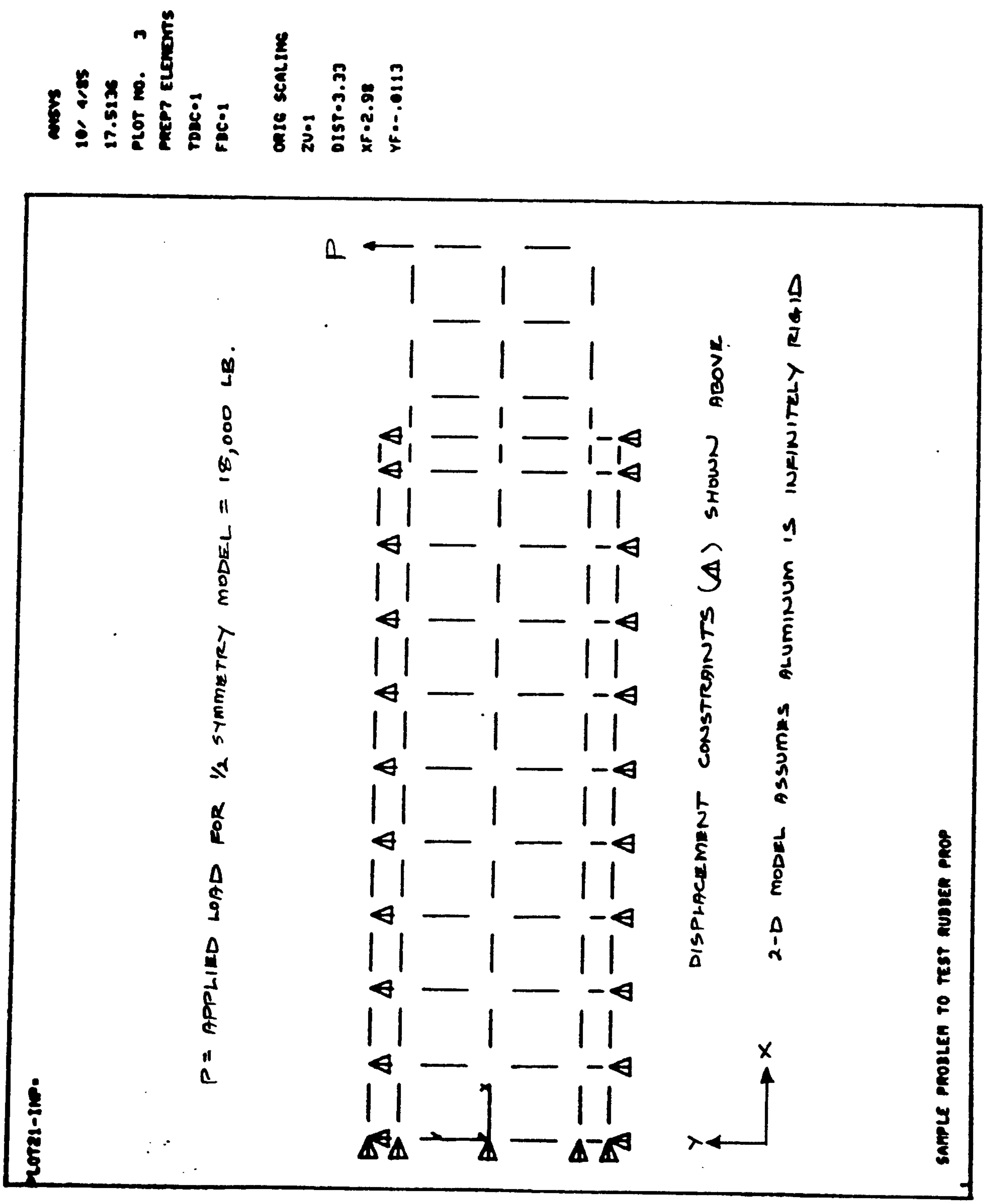


Figure B-4 - 2-D Model Boundary Conditions

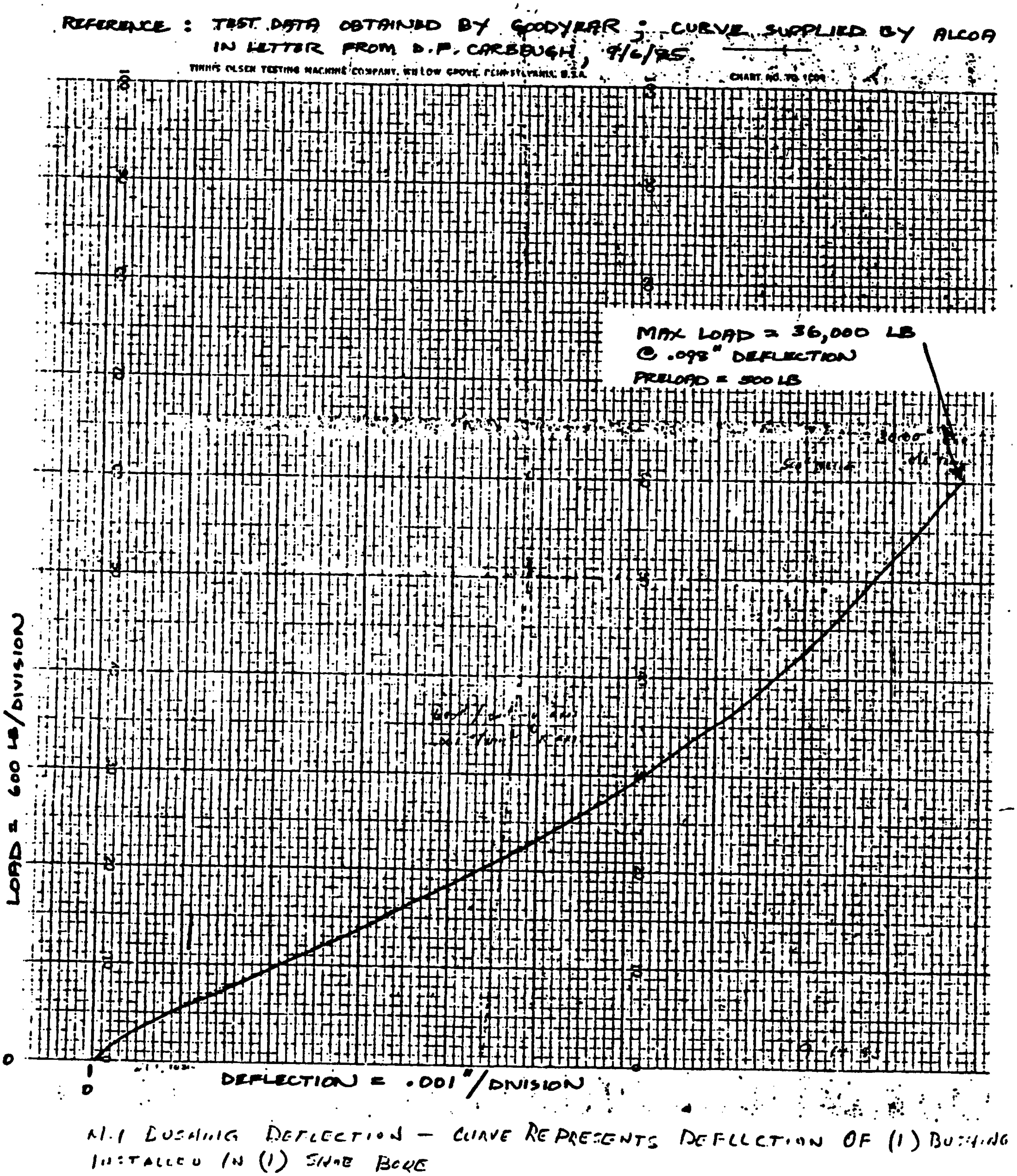


Figure B-5 - Load-Deflection Curve of M-1 Bushing Assembly for One Pin/Bushing Installed in One Binocular

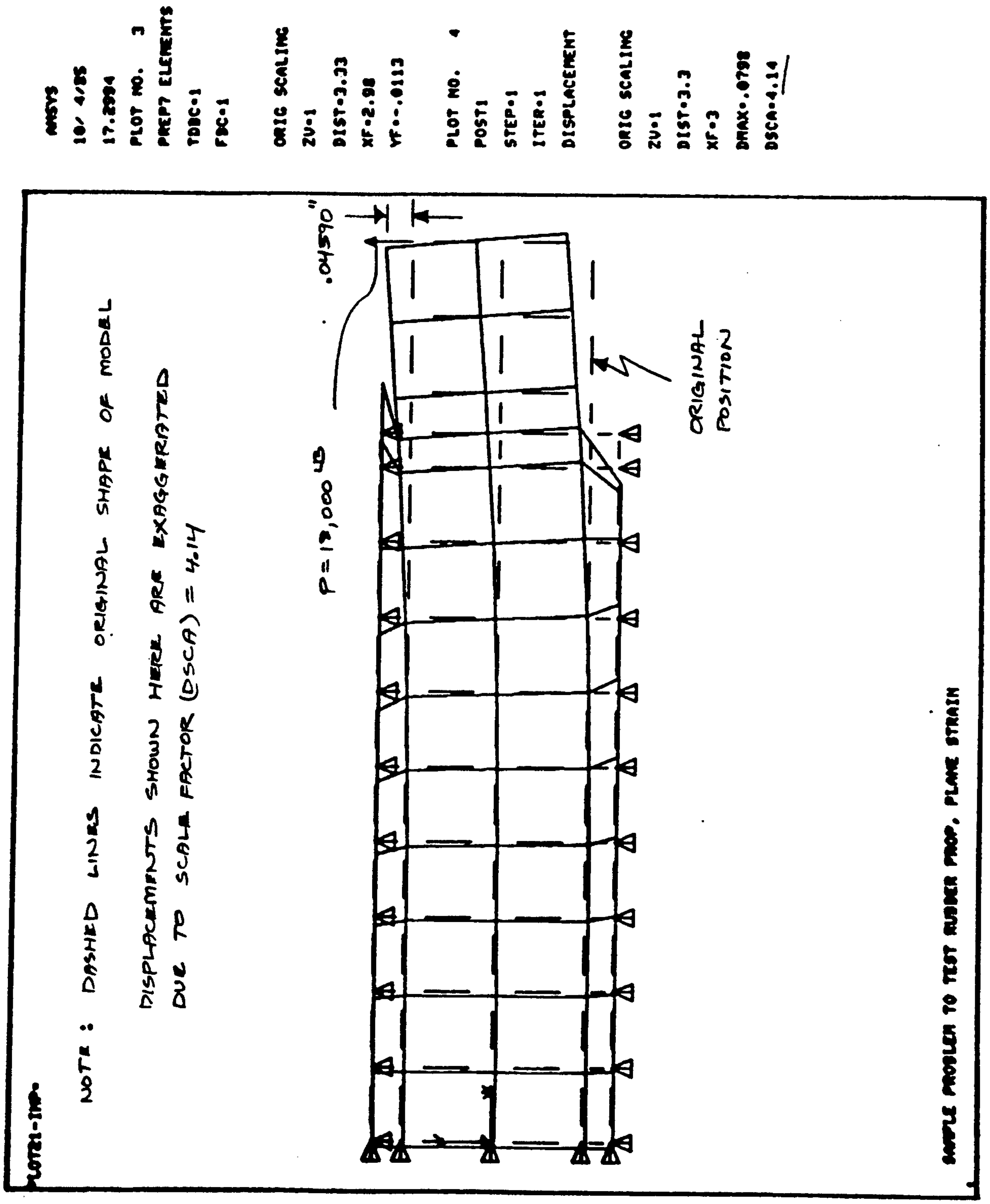


Figure B-6 - Displacement Plot for Plane Strain Case,
Displacement Scale = 4.14

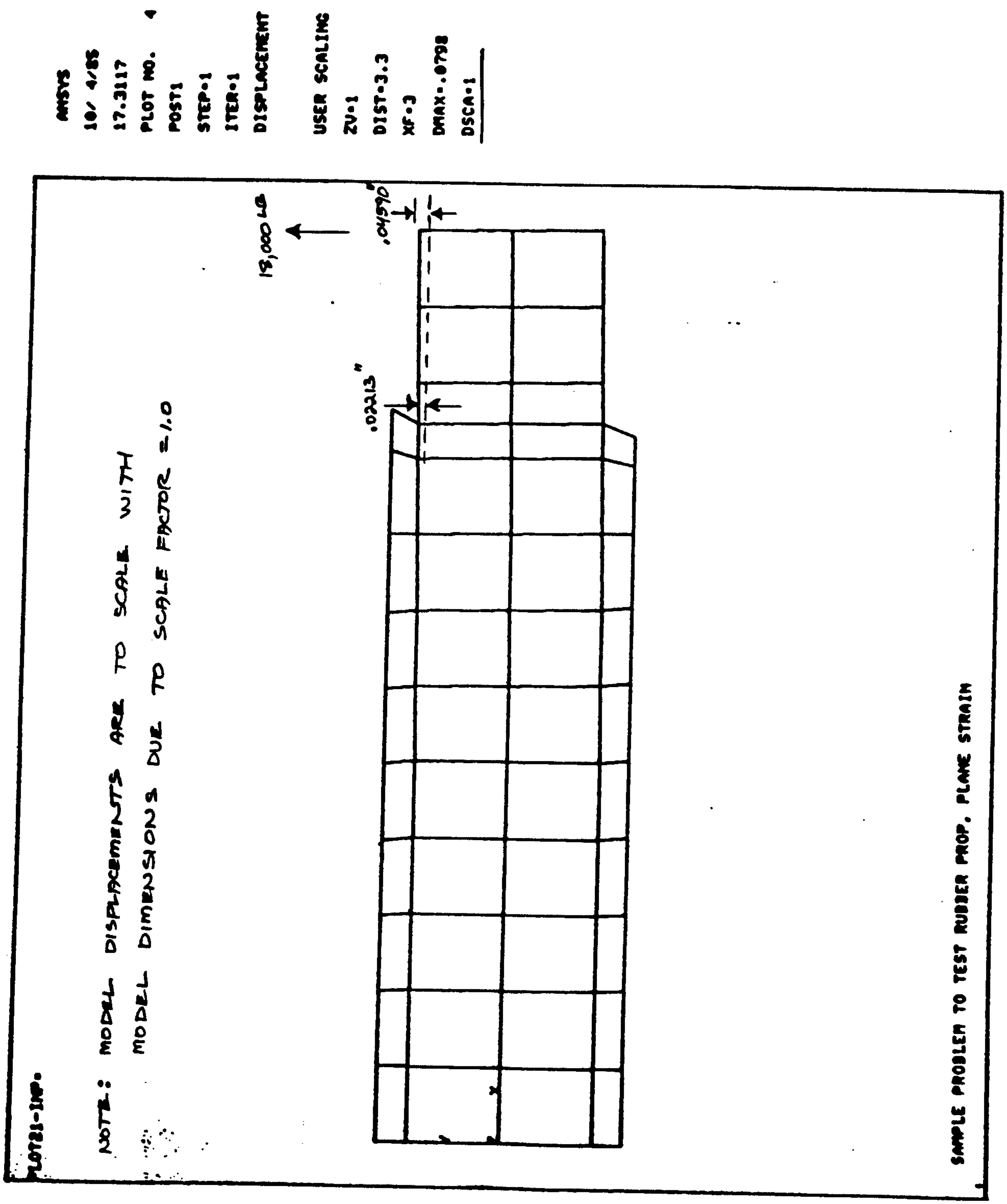


Figure B-7 - Displacement Plot for Plane Strain Case,
Displacement Scale = 1.0

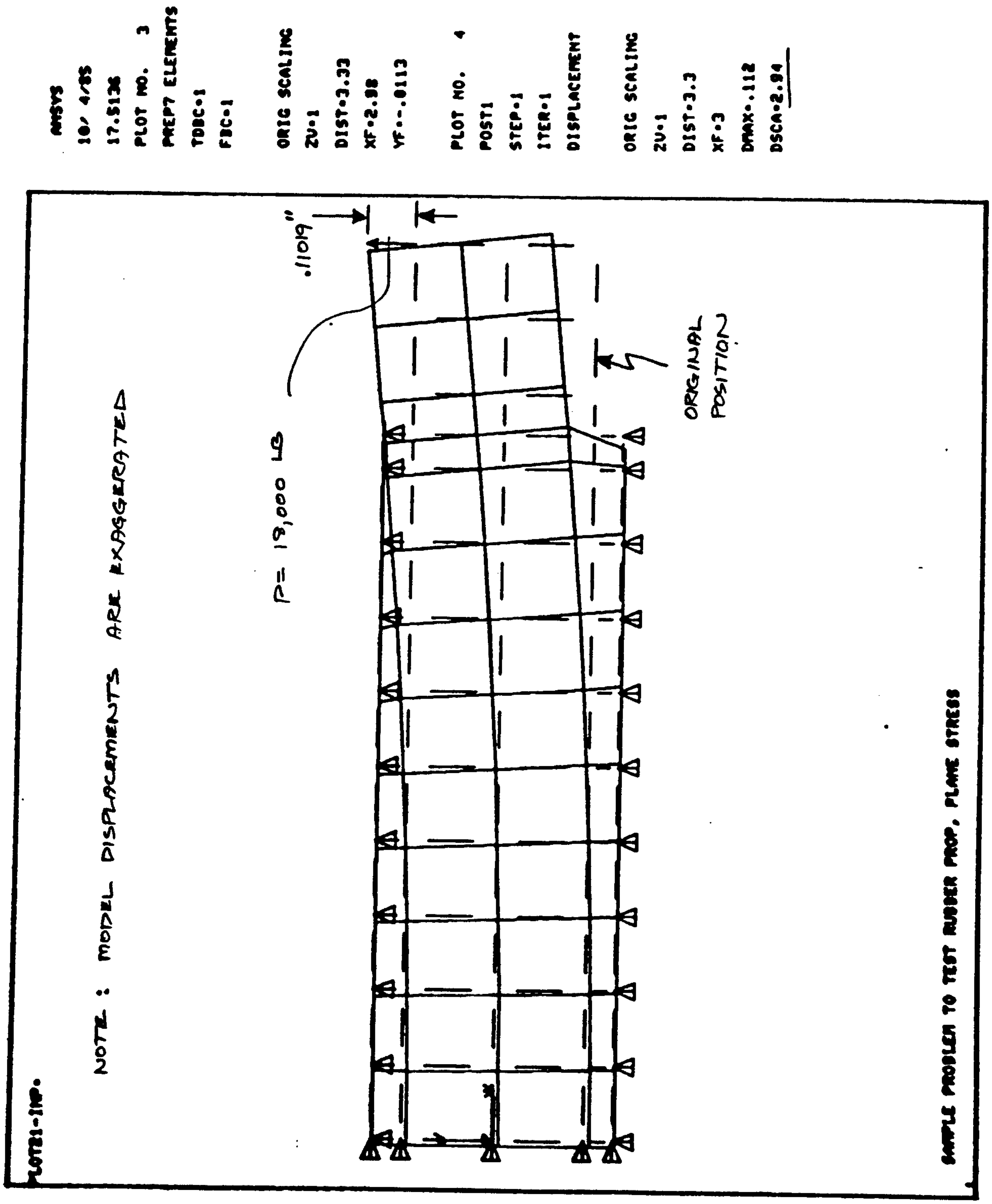


Figure B-8 - Displacement Plot for Plane Stress Case,
Displacement Scale = 2.94

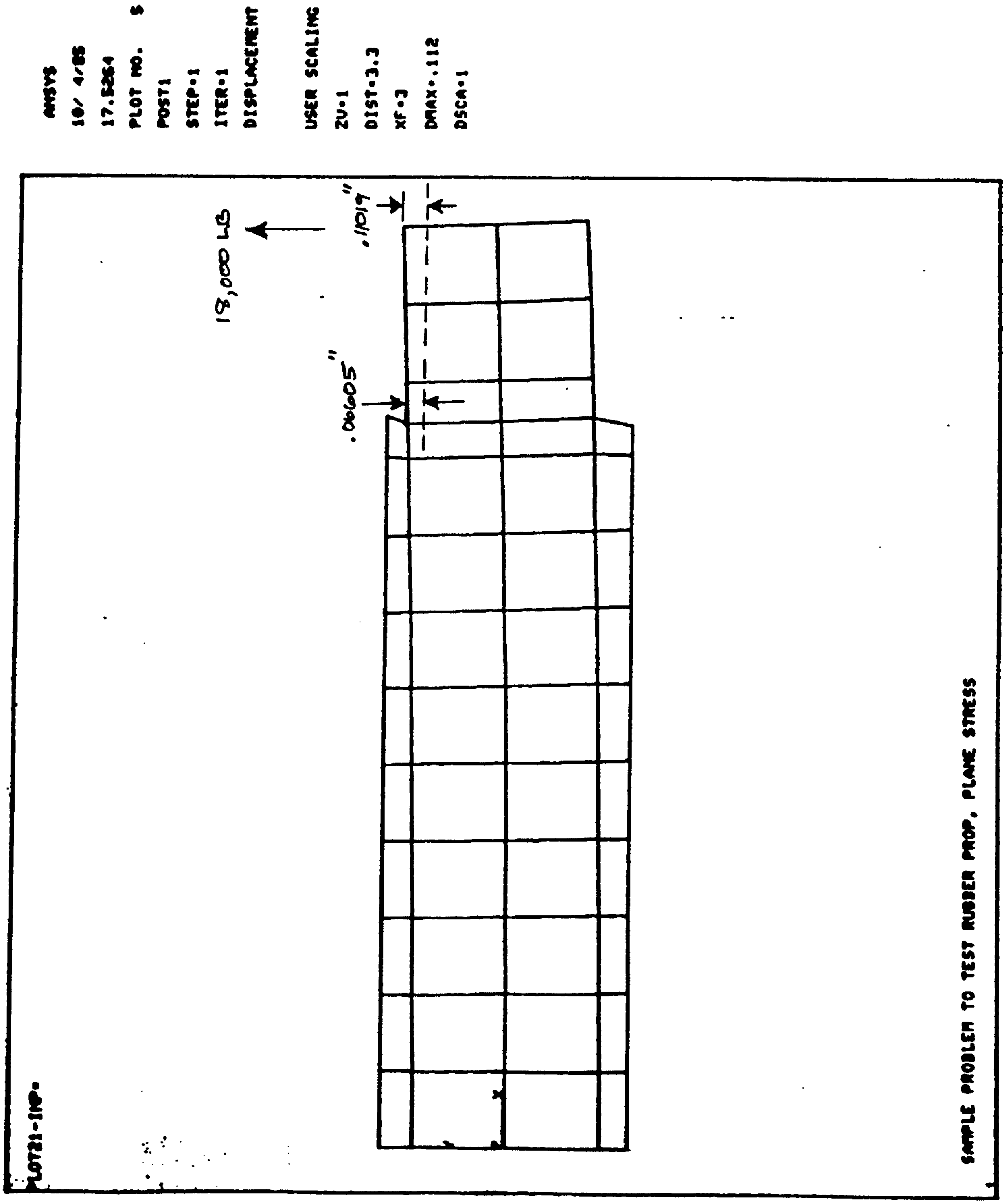


Figure B-9 - Displacement Plot for Plane Stress Case,
Displacement Scale = 1.0

APPENDIX C

Parametric Studies of a 2-D Interaction Model of the Shaft, Rubber, and Shoe Endplate

The purpose of this study was to investigate the interaction of the shaft, rubber, and endplate due to a tensile pull load using an economical model. The sensitivity of the rubber modulus and the effect of rubber preload were investigated in this study. These results were used to guide the 3-D model analysis presented in Section 5.0 and to gain some insight into the load paths of the assembly. These studies were run on the Data General MV-8000 computer at Swanson Analysis Systems, Inc. for the sake of expediency.

The 2-D ANSYS plane model of the shoe endplate is shown in Figure C-1. This model is identical to a slice taken through the 3-D model endplate section as described in Section 2.0 of the report. The model is constructed of the ANSYS STIF42 solid elements using the plane stress option. The nodal point locations are shown in Figure C-2.

The model was loaded by a 10,000 lb. load applied to the shaft. This load was considered to be representative of the load being carried by the endplate in the 3-D model. The actual magnitude of the load is not significant, although it should be representative, and it was held constant throughout the study. The material properties for the steel and aluminum are the same as in the 3-D model. The rubber modulus was varied from 20,000 psi to 7,000 psi and Poisson's ratio for rubber was set to zero. As discussed in Section 5.2, Poisson's ratio for rubber was set to zero for the 3-D model and this model in order to eliminate the rigid cube effect due to the incompressible nature of rubber and the modeling approach used for the rubber.

Five parametric load cases were investigated with this model and the significant results are summarized in Table C-1. Case 4 is very similar to Case 5 and is not included in the summary. The only difference between Cases 4 and 5 is that the rubber preload was set to .10 inches for Case 4. The parameters that were varied in the studies are listed in the top four rows of the table. Selected stress and displacement results are listed in the remainder of the table. Figure C-3 shows the location of the three key stress points in the shoe model. The ANSYS input listing for Case 5 is shown in Table C-2.

Cases 1 and 2 compare the effect of the rubber modulus, 20,000 psi vs. 7,000 psi. Although the rubber modulus was reduced by almost a factor of three, the aluminum shoe stresses only increased by 10% or less. The shaft deflection increased by approximately a factor of three which is a direct result of the modulus change.

Displacement and stress contour plots for Cases 1 and 2 are shown in Figures C-4 to C-11. One displacement plot and three stress contour plots are shown for each case. Figure C-4 shows an exaggerated distortion plot of the model. Note that the maximum displacement is only .0292" and the scale factor is 7.11 which exaggerates the motions. A scale factor of 1.0 would show actual displacements to scale with the model dimensions. Figures C-5 and C-6 show the first principal stress contours (SIG1) and the third principal stress contours (SIG3), respectively. Figure C-7 shows the stress intensity contour plot. The distorted shape of the shoe (dashed lines) on the stress plots show that the binocular tends to ovalize under load. The maximum tensile stresses occur at points A and C which is consistent with the stress distributions in a circular ring under

diametral loading. Figures C-8 through C-11 show the same set of plots for Case 2. All stress values listed in Table C-1 were obtained directly from the contour plots. All extrapolated values are indicated with the approximate sign (~).

The 2-D model was modified to include a ring of gaps (ANSYS STIF12) between the rubber and aluminum shoe elements. This model was used to analyze Cases 3, 4, and 5 for the purpose of evaluating rubber separation and preload. Case 3 is the same as Case 2 except that the rubber was allowed to pull away from the aluminum as shown in Figure C-12. As indicated in Table C-1, the maximum tensile stresses for Case 3 are approximately twice those of Case 2. This is due to the fact that the preload was overcome (preload was set to zero for Case 3) and the rubber was allowed to separate. This separation effectively cuts the rubber stiffness in half and allows more deflection and higher stresses in the aluminum. See the UY deflection at Node 590 for Cases 2 and 3 in Table C-1. Figures C-13 to C-15 show the stress contour plots for Case 3.

Case 5 extends Case 3 by preloading the rubber before the external load is applied. This case demonstrates the importance of the rubber preload on the shoe stresses. Case 5 was run in two load steps: Load step 1 is the preload and load step 2 is the preload plus external load. Figure C-16 shows the displacement plot for the preload step. Note that the preload is shown as a gap in the model for illustration purposes only. ANSYS graphics handles gaps in this manner. The actual hardware obviously does not have a gap. Figures C-17 to C-19 show the

stress contour plots for the preload case. The maximum preload principal stress is approximately 13,000 psi (Figure C-17).

Figures C-20 to C-23 show the set of plots for load step 2 of Case 5. The stresses for Case 5 are also summarized in Table C-1. Note that the third column of Case 5 is the difference between the first two columns and represents the effect of the applied load without preload. This result is very significant in that it is approximately equal to the Case 2 results. Remember that Case 2 is only a one load step problem without explicitly modeling the gap interface and preload interference step. This means that, as long as the preload is maintained, the problem can be modeled as a linear system without gaps and preload and that the rubber elements can take both compression and tension. Preload stresses can be superposed on Case 2 stresses if desired. The slight difference in stresses between the Case 2 and Case 5 subtracted results can be attributed to the friction free interface between the rubber and aluminum for Case 5. Since the Case 2 model is continuous across the three materials, shear forces can be transmitted across the boundary and thus have some effect on the stress pattern.

Conclusions

Based on the results of these parametric studies, the following observations can be made:

1. The value of Young's modulus assumed for the rubber has a very small effect on the resulting aluminum shoe stresses. The modulus of rubber,

however, has a significant effect on the shaft displacement within the binocular. Compare Cases 1 and 2.

2. The rubber preload has a significant effect on the aluminum shoe stresses. When the rubber preload is exceeded or separation occurs, the shoe stresses are higher than they would be if adequate preload were maintained. Compare Cases 3 and 5.

3. As long as rubber preload is maintained, the track shoe system can be modeled as a linear system with the rubber capable of supporting both tensile and compressive loads. The tensile loads are only reducing the compressive preload in the rubber. Compare Cases 2 and 5. This conclusion is significant in that the detailed 3-D model of the shoe can be analyzed as a linear system without gaps and costly iterations to achieve convergence.

TABLE C-1
2-D MODEL PARAMETRIC STUDIES
SUMMARY OF RESULTS[1]

	Case 1	Case 2	Case 3	Case 5		
				Preload	Total	Load Only[4]
Load (Lbs)	-10,000	-10,000	-10,000	0	-10,000	-10,000
E, Rubber (PSI)	20,000	7,000	7,000	7,000	7,000	7,000
Gaps	No	No	Yes	Yes	Yes	No
Rubber Preload	0	0	0	.13"	.13"	0
SIGPR[2] @ PT. A[3]	15,346	16,340	34,365	~9,500	26,693	~17,200
SIGPR @ PT. B	~-5,000	~-5,500	~-7,000	12,774	~7,500	~-5,300
SIGPR @ PT. C	~9,500	~10,000	~22,000	~6,500	~18,000	~11,500
δ_{shaft}, UY @ N470	-.02917"	-.08034"	-.24061"	-.00067"	-.12039"	-.11972"
δ_{shoe}, UY @ N590	-.00345"	-.00363"	-.00682"	-.00120"	-.00509"	-.00389"

Notes: [1] Case 4 is very similar to Case 5 and is not shown in this table. The Case 4 rubber preload was set to .10".

[2] SIGPR is the principal stress and can be either SIG1 or SIG3 depending whether the largest stress is positive or negative.

[3] See Figure C-3 for locations.

[4] This column was calculated by subtracting the preload column from the total column.

TABLE C-2
ANSYS Input Listing for Plane Model Case 5

```
LI 1 103
/PREP7
/NOPR
/TITLE,    ALCOA TANK SHOE  PLANE MODEL  - TENSILE
ET,1,42                       *** SHAFT
ET,2,42                       *** RUBBER
ET,3,42                       *** BINOCULAR
ET,4,42                       *** THICK BACK PLATE
ET,5,12                        *** GAP ELEMENTS
C***  MATL 1  STEEL
EX,1,30.0E6
ALPX,1,0.
NUXY,1,.3
DENS,1,.283
MU,1,0.
C***  MATL 2  RUBBER
EX,2,7.0E3
ALPX,2,0.
NUXY,2,0.
DENS,2,0.0336
C***  MATL 3 ALUMINUM
EX,3,10.0E6
ALPX,3,0.
NUXY,3,.33
DENS,3,0.098
C***
C***  REAL CONSTANTS
C***
R,1,-90,1E8,0.13
RP24,1,15
C***
C***   SHAFT,RUBBER BUSHING,BINOCULAR NODES
C***
LOCAL,12,1,1.8,1.3
CSYS,12
N,452,.36875
N,476,.6875
N,500,.8905
N,572,1.3
FILL,500,572,1,548
NGEN,24,1,452,476,24,,15.
NGEN,24,1,476,500,24,,15.
NGEN,24,1,500,548,48,,15.
NGEN,24,1,548,572,24,,15.
NGEN,2,24,500,523,1
C***  ROTATE NODES
CSYS,12
NROTAT,500,547,1
C***
C***  NODES - THICK BACK PLATE
C***
CSYS
N,4001,3.1,1.6365
N,4014,3.1,1.95
N,4027,3.1,2.4258
N,4028,2.9258,2.4258
N,4029,2.7192,2.4258
N,4040,3.1,2.7198
N,4041,2.9258,2.7198
N,4042,2.7192,2.7198
N,4043,2.45,2.7198
N,4044,2.1365,2.7198
N,4045,1.80,2.7198
N,4046,1.4635,2.7198
N,4047,1.15,2.7198
N,4048,.88076,2.7198
NGEN,5,13,4040,4048,1,,.2623
N,4035,.88076,2.4258
N,4049,.67417,2.7198
N,4052,,2.7198
FILL,4049,4052,2,4050,1
NGEN,5,13,4049,4052,1,,.2623
N,4036,.67417,2.4258
N,4039,,2.4258
FILL,4036,4039,2,4037,1
N,4024,.44945,1.74903
N,4026,,1.74903
FILL,4024,4026,1,4025
N,4030,.67417,2.2192
FILL,4024,4037,1,4031
RP3,1,1,,1
C***
C***  SHAFT ELEMENTS
C***
TYPE,1
MAT,1
E,452,453,477,476
EGEN,23,1,-1
E,475,452,476,499
C***
C***  RUBBER ELEMENTS
C***
TYPE,2
MAT,2
E,476,477,501,500
EGEN,23,1,-1
E,499,476,500,523
MAT,1
TYPE,5
REAL,1
E,500,524
EGEN,24,1,-1,,,,,1
C***
C***  BINOCULAR ELEMENTS
*
```

TABLE C-2
(Continued)

```
LI 104 LA
C***
TYPE,3
MAT,3
E,524,525,549,548
EGEN,2,24,-1
EGEN,23,1,-2
E,547,524,548,571
E,571,548,572,595
C***
C***  THICK BACK PLATE ELEMENTS
C***
TYPE,4
MAT,3
E,4040,4053,4054,4041
EGEN,12,1,-1
EGEN,4,13,-12
E,4035,4048,4049,4036
EGEN,4,1,-1
E,4024,4031,4032,4025
RP2,7,6,6,7
EGEN,2,1,-2
E,583,582,4024,4024
E,582,4030,4031,4024
E,4030,4036,4037,4031
E,582,581,4030,4030
E,581,4035,4036,4030
E,581,580,4035,4035
E,580,4047,4048,4035
E,579,4046,4047,580
E,578,4045,4046,579
E,577,4044,4045,578
E,576,4043,4044,577
E,575,4029,576,576
E,4029,4042,4043,576
E,574,4028,4029,575
E,4028,4041,4042,4029
E,572,4001,573,573
E,4001,4014,574,573
E,4014,4027,4028,574
E,4027,4040,4041,4028
ITER,1,1,1
D,4092,UY,0.
RP13,1
D,4092,UX,0.
CPSIZE,50
CPNGEN,1,UY,452,499,1
F,452,FY,0.
LWRITE
ITER,-3,3,3
F,452,FY,-10000.
LWRITE
AFWRITE,,1
FINISH
/INPUT,27
FINISH
/POST1
SET,1,1
/ANGLE,,-90
/VIEW,,,,-1
ERSEL,TYPE,1,4
PLDISP,0
PLDISP,1
PLDISP,2
NALL
EALL
ERSEL,TYPE,3,4
/EDGE,,1
NELEM
PLNSTR,SIG1
PLNSTR,SIG3
PLNSTR,SI
ERSEL,TYPE,3
NSORT,SI,,,15
PRNSTR,PRIN
EUSEL
ERSEL,TYPE,4
NSORT,SI,,,15
PRNSTR,PRIN
NALL
EALL
SET,2,3
/EDGE
/ANGLE,,-90
/VIEW,,,,-1
ERSEL,TYPE,1,4
PLDISP,0
PLDISP,1
PLDISP,2
NALL
EALL
ERSEL,TYPE,3,4
/EDGE,,1
NELEM
PLNSTR,SIG1
PLNSTR,SIG3
PLNSTR,SI
ERSEL,TYPE,3
NSORT,SI,,,15
PRNSTR,PRIN
EUSEL
ERSEL,TYPE,4
NSORT,SI,,,15
PRNSTR,PRIN
FINISH
x
```

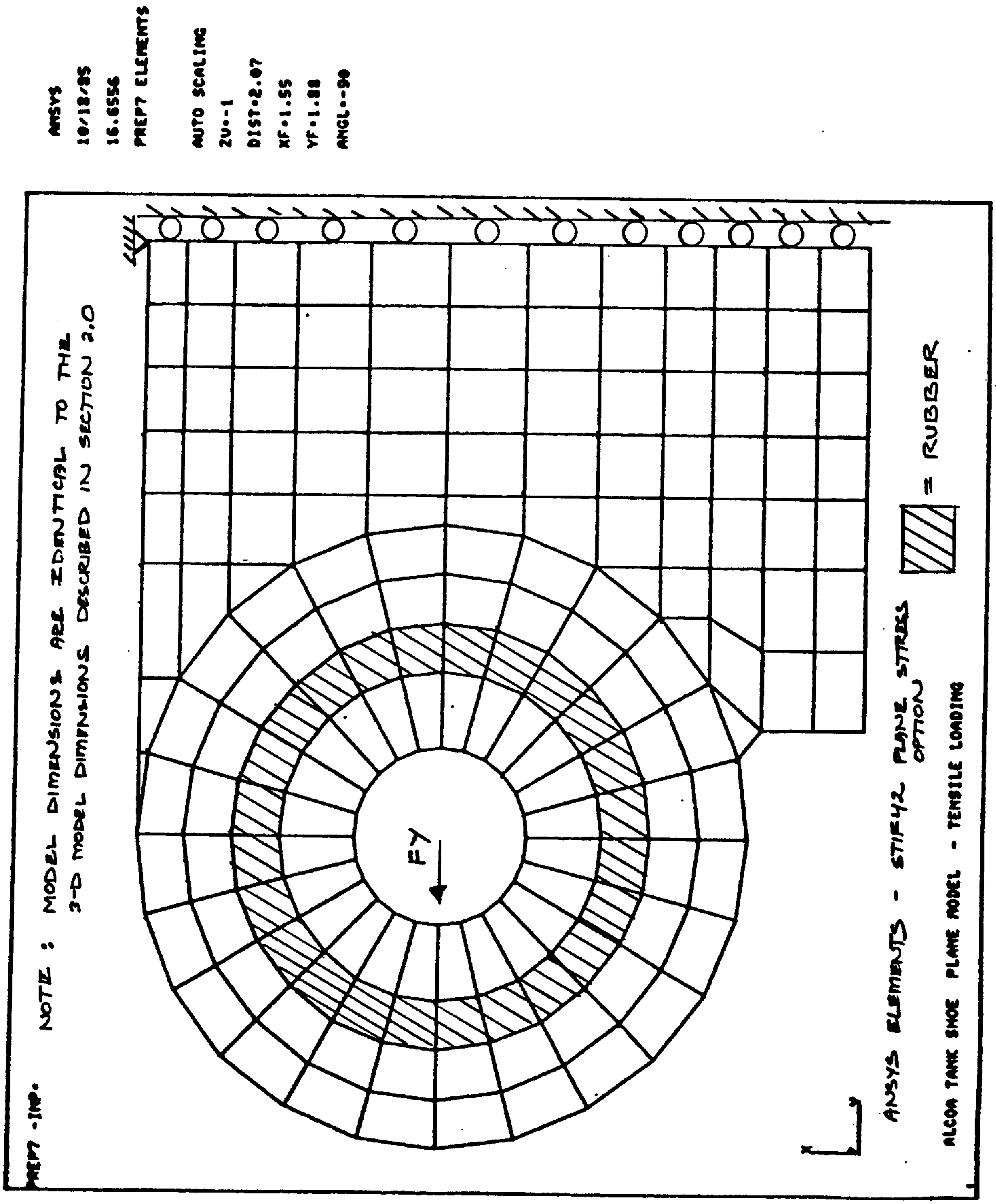


Figure C-1 - 2-D ANSYS Interaction Model of the Shaft, Rubber, and Shoe Endplate

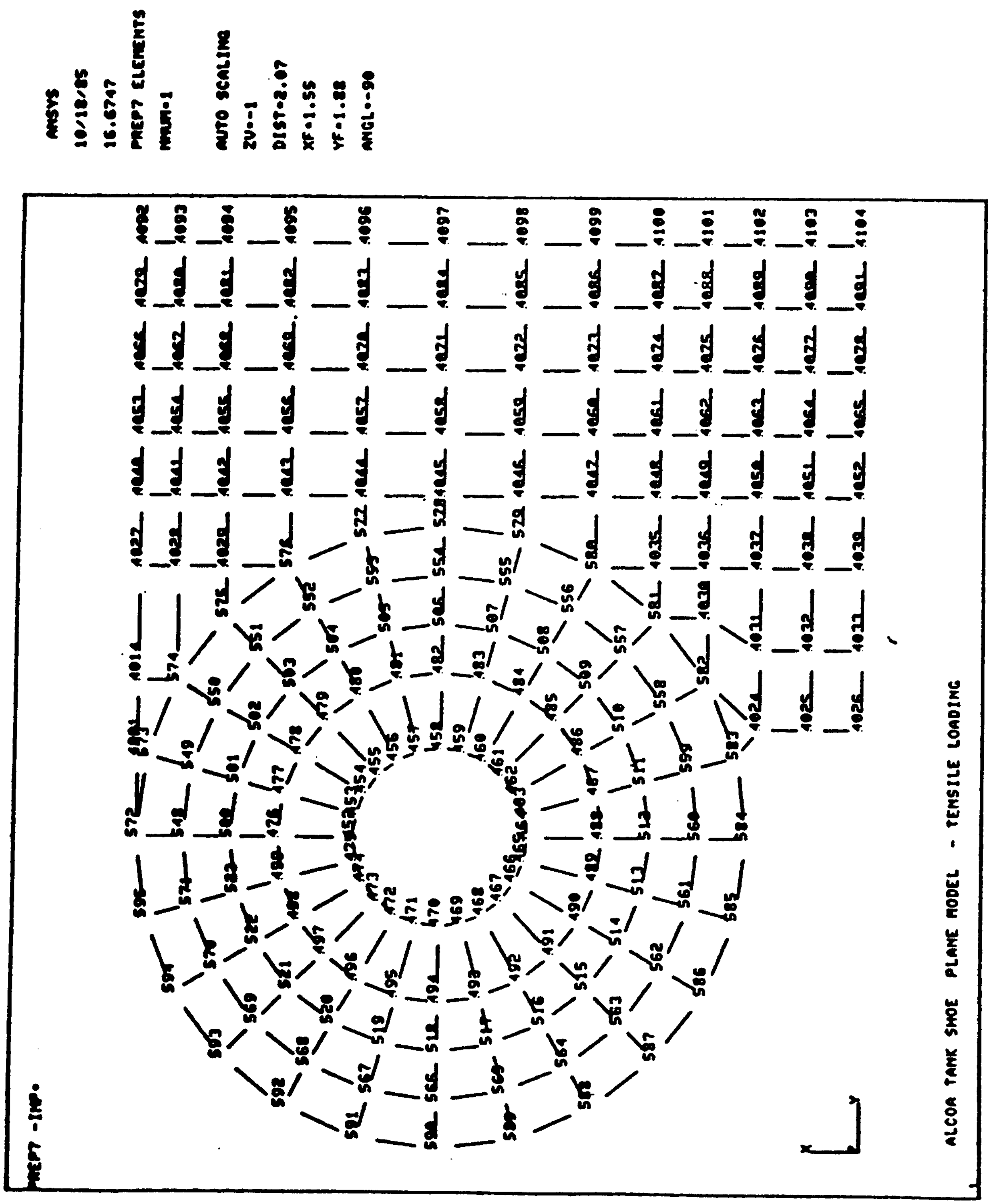


Figure C-2 - Node Point Description for 2-D Plane Model

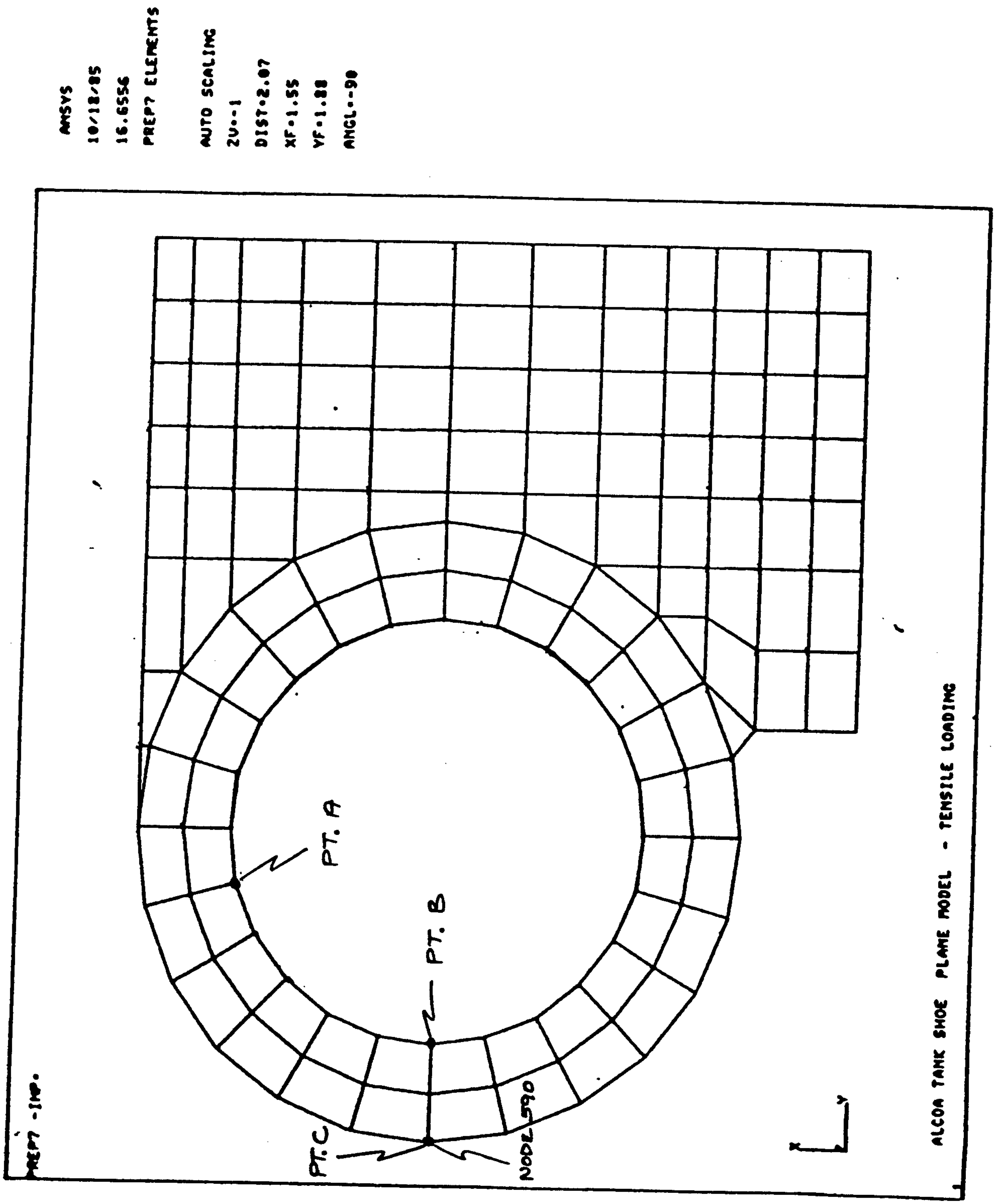


Figure C-3 - Sketch of Shoe Model Showing High Stress Locations

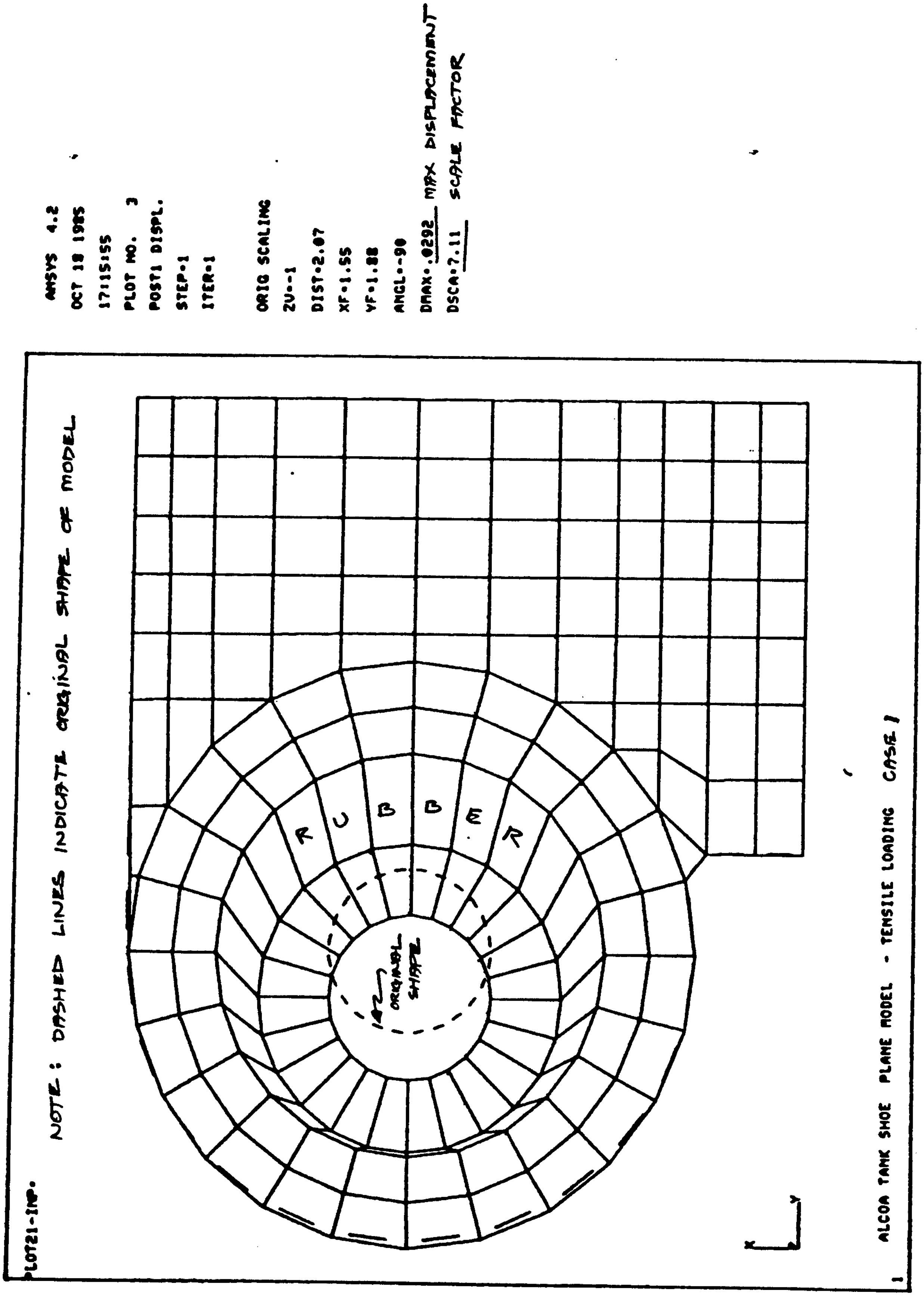


Figure C-4 - Plane Model, Case 1, Displacement Plot

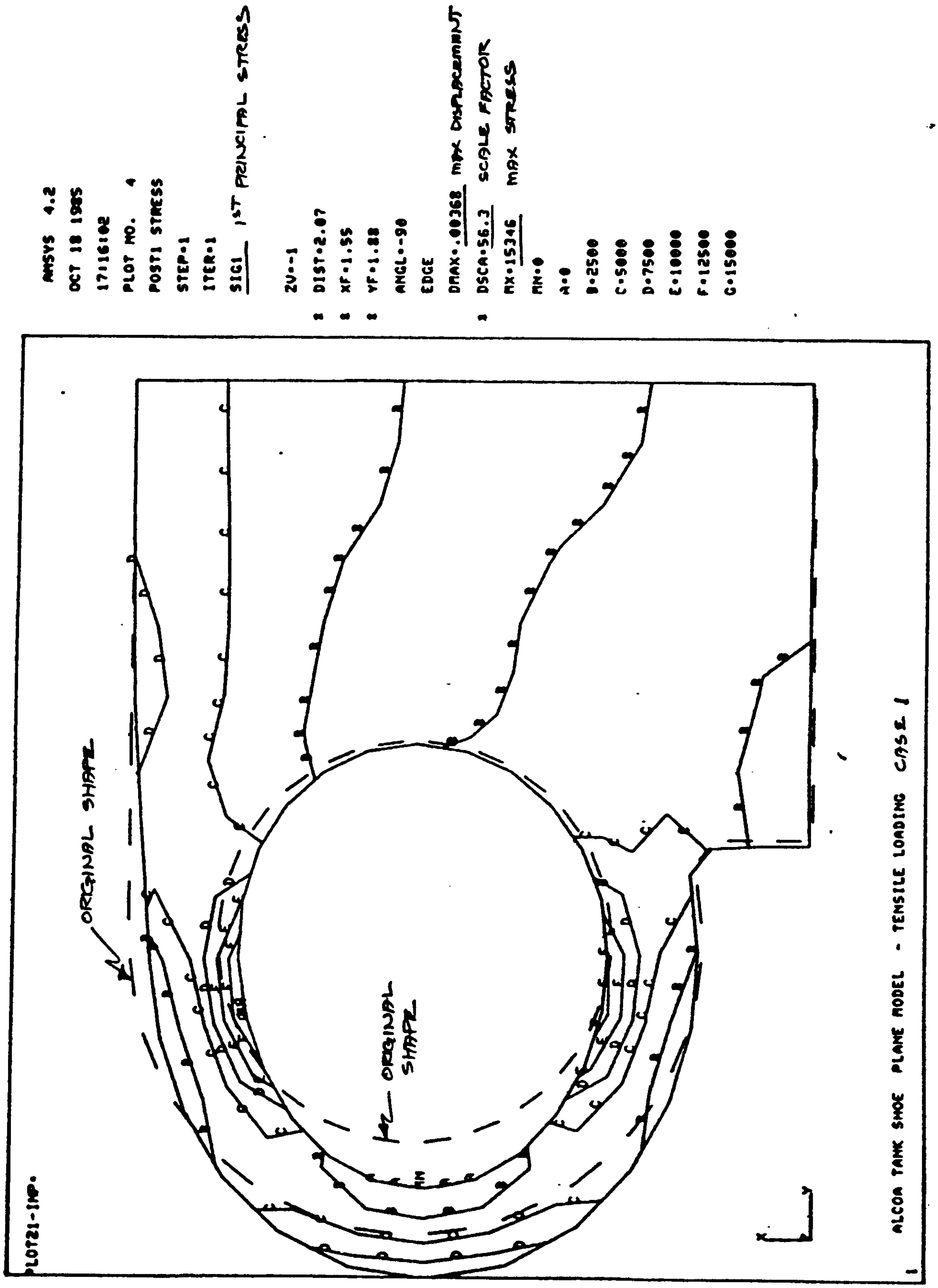


Figure C-5 - Plane Model, Case 1, SIG1 Principal Stress

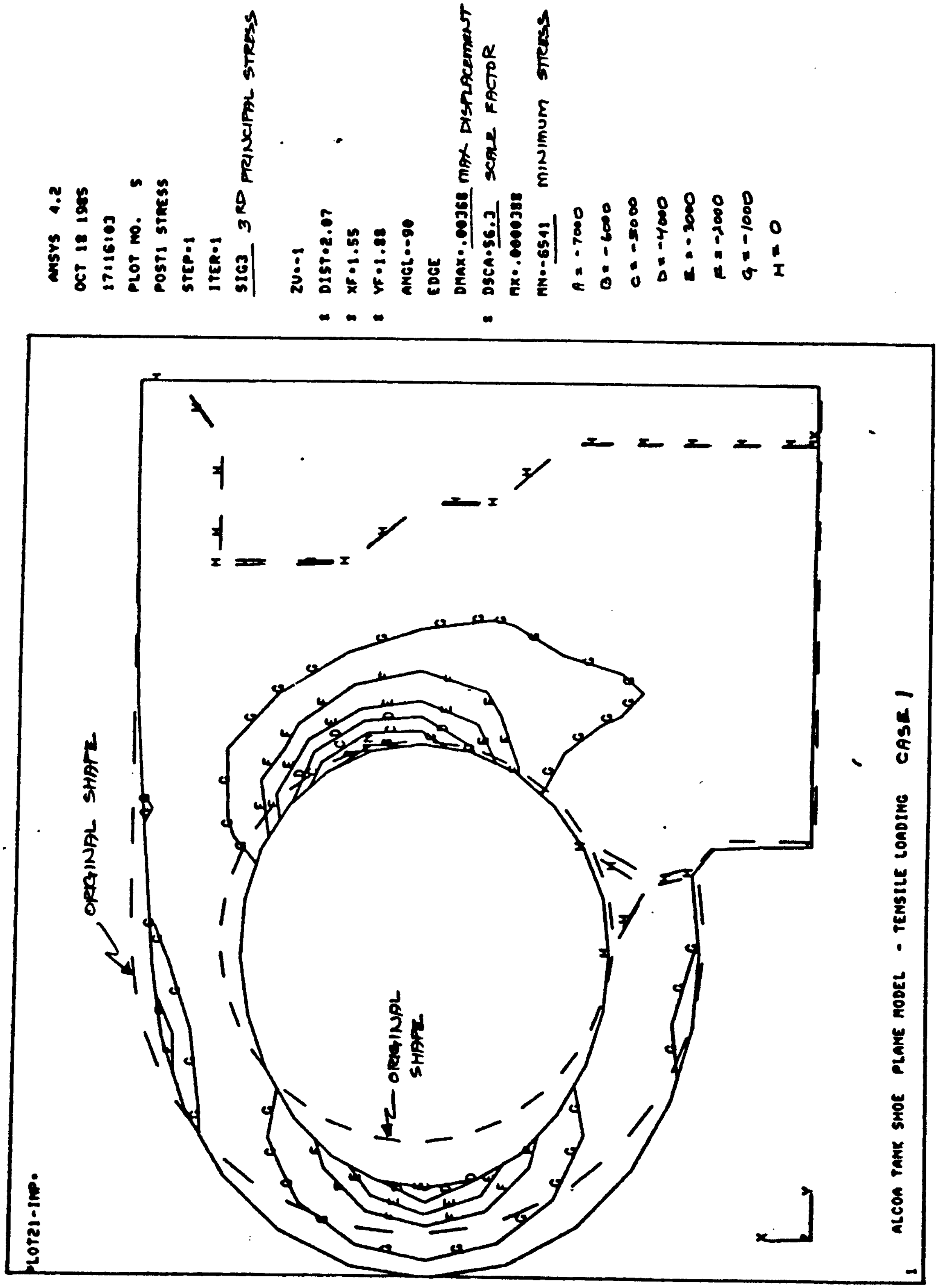


Figure C-6 - Plane Model, Case 1, SIG3 Principal Stress

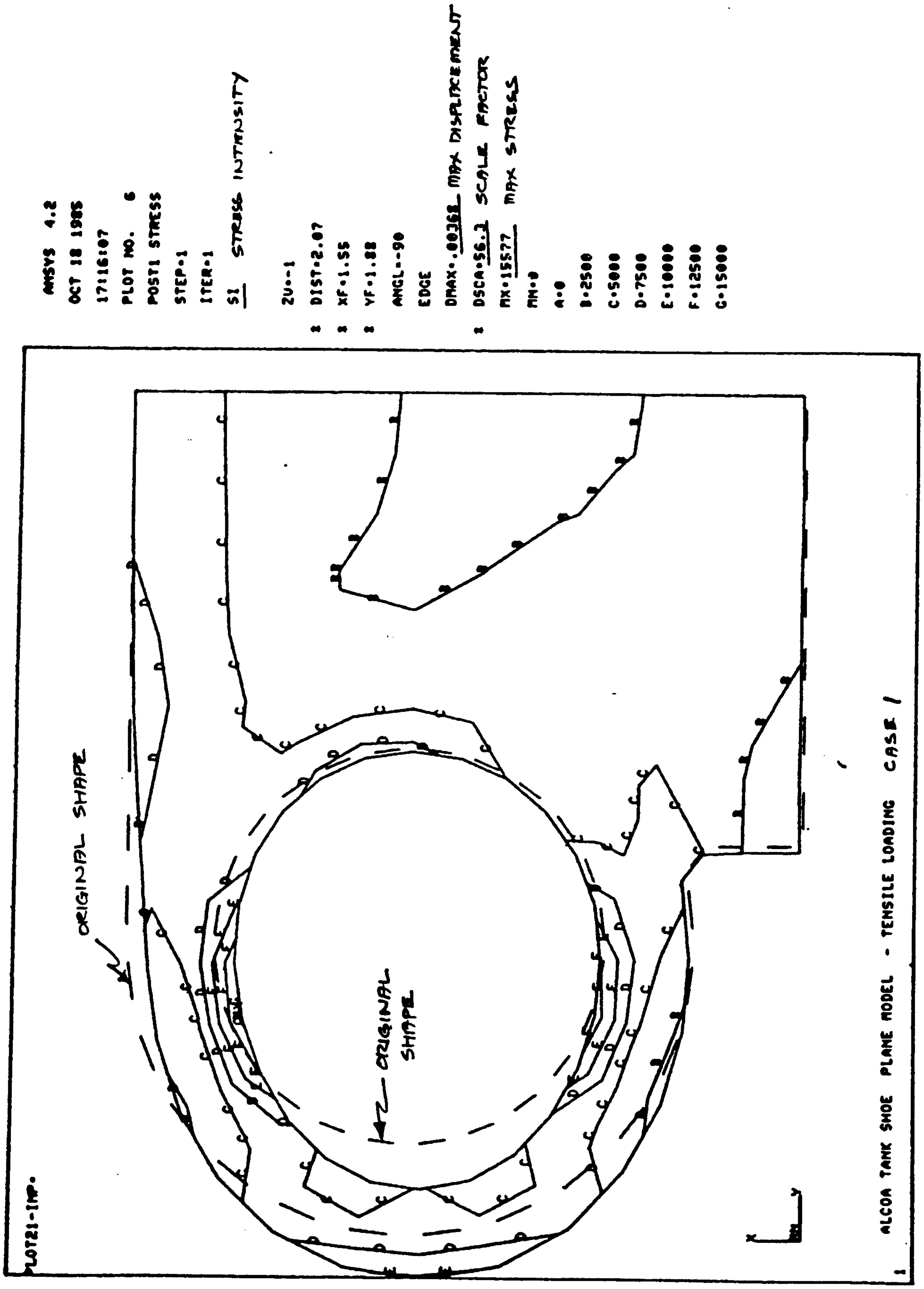


Figure C-7 - Plane Model, Case 1, Stress Intensity

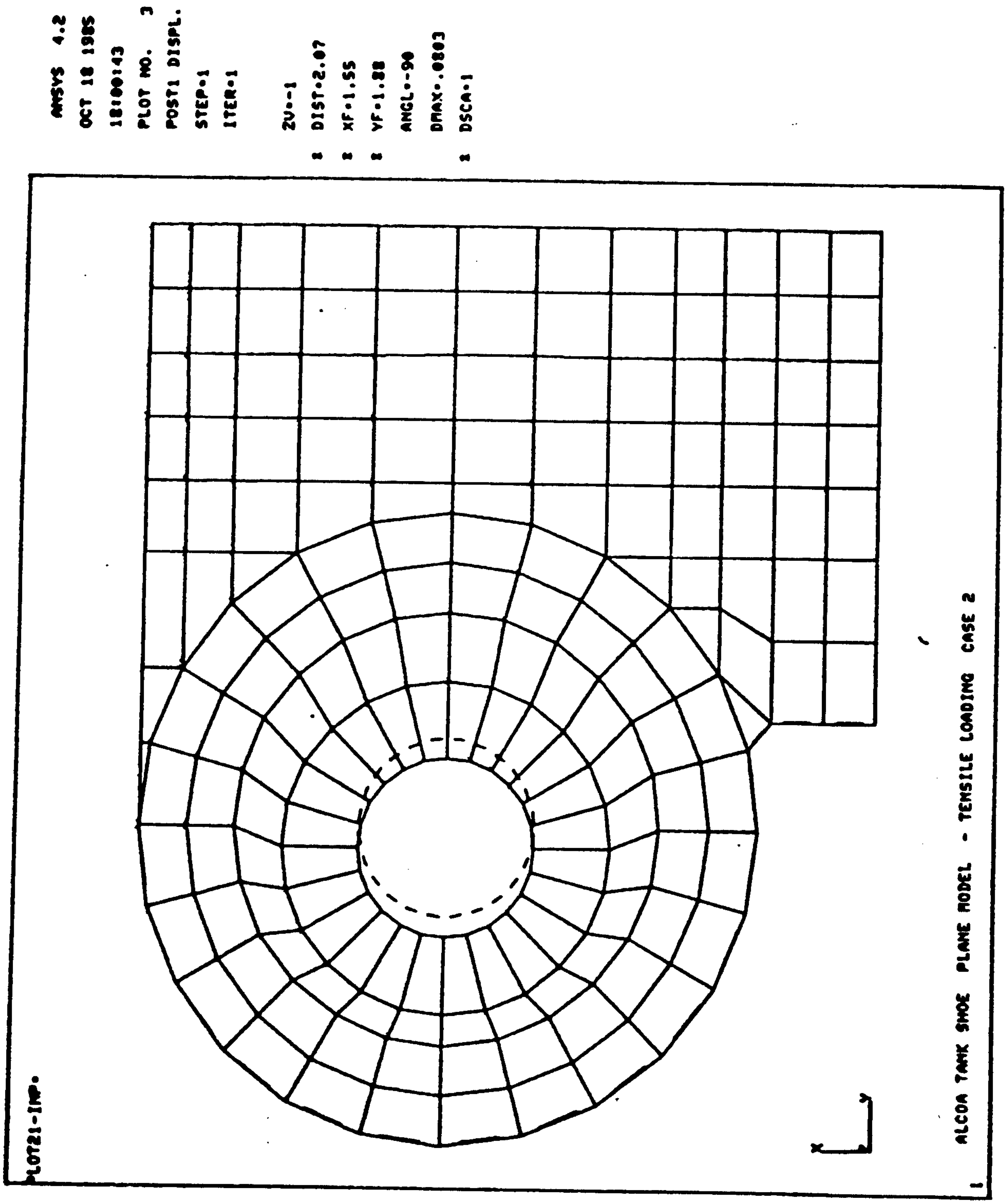


Figure C-8 - Plane Model, Case 2, Displacement Plot

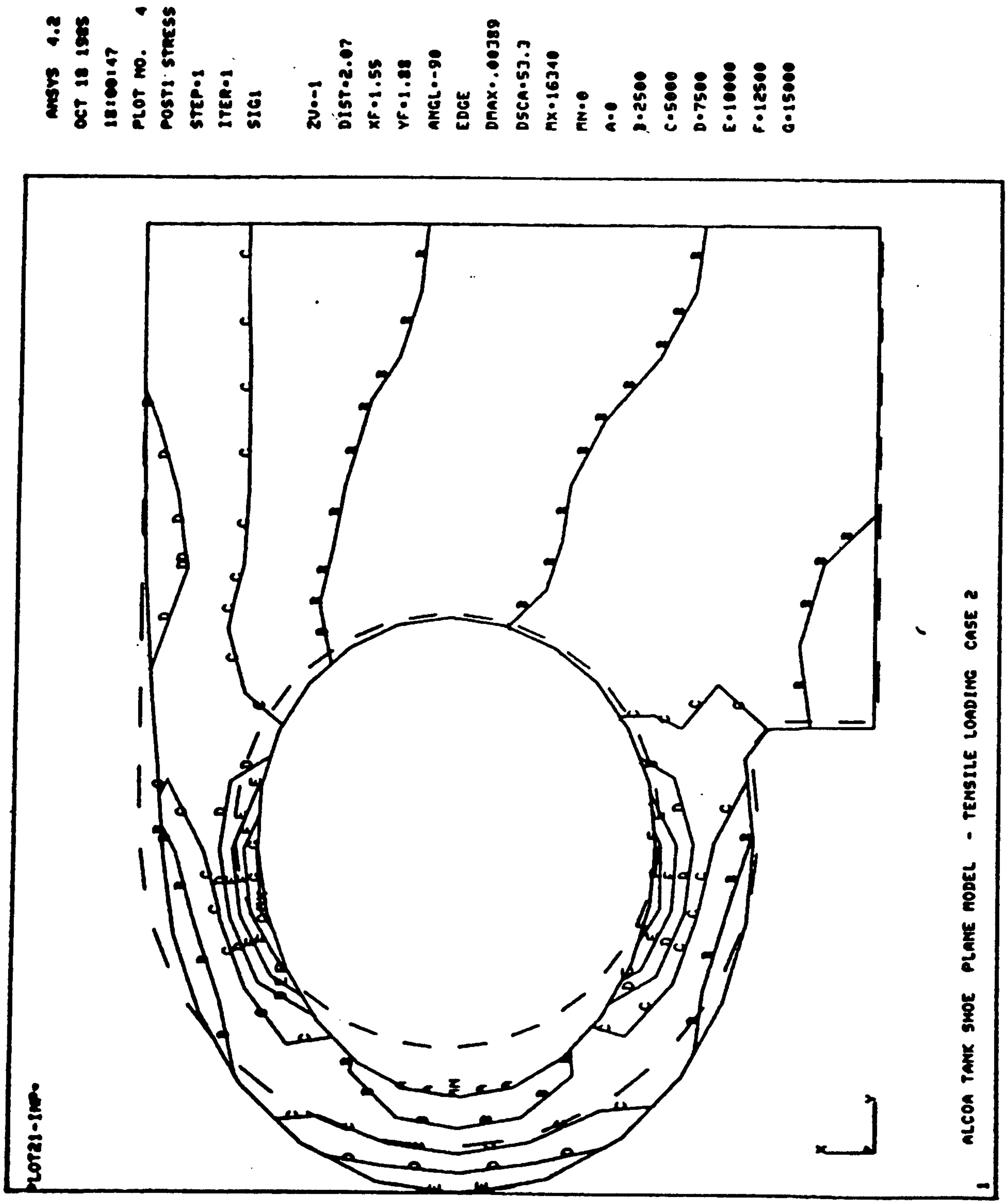


Figure C-9 - Plane Model, Case 2, SIG1 Principal Stress

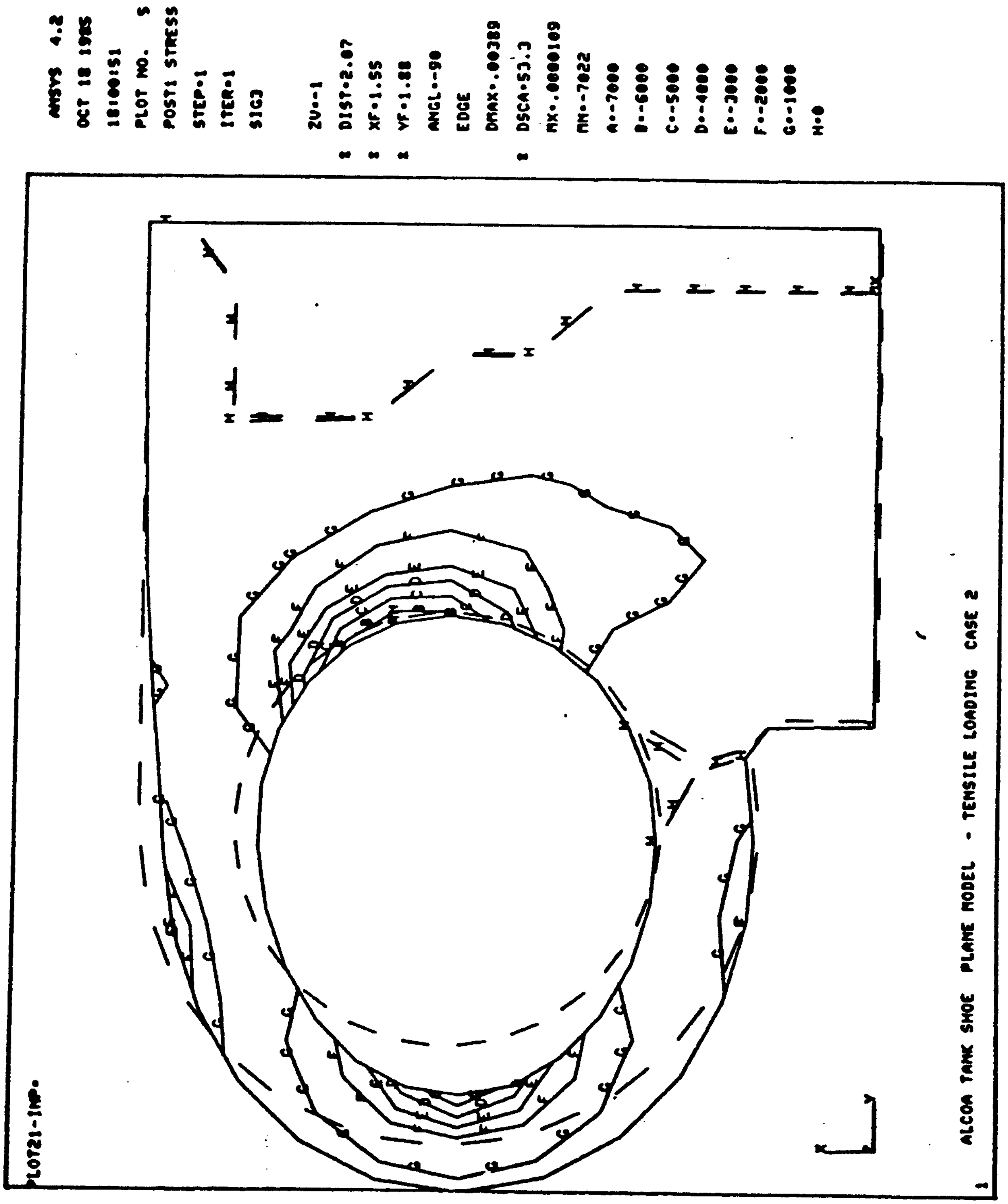


Figure C-10 - Plane Model, Case 2, SIG3 Principal Stress

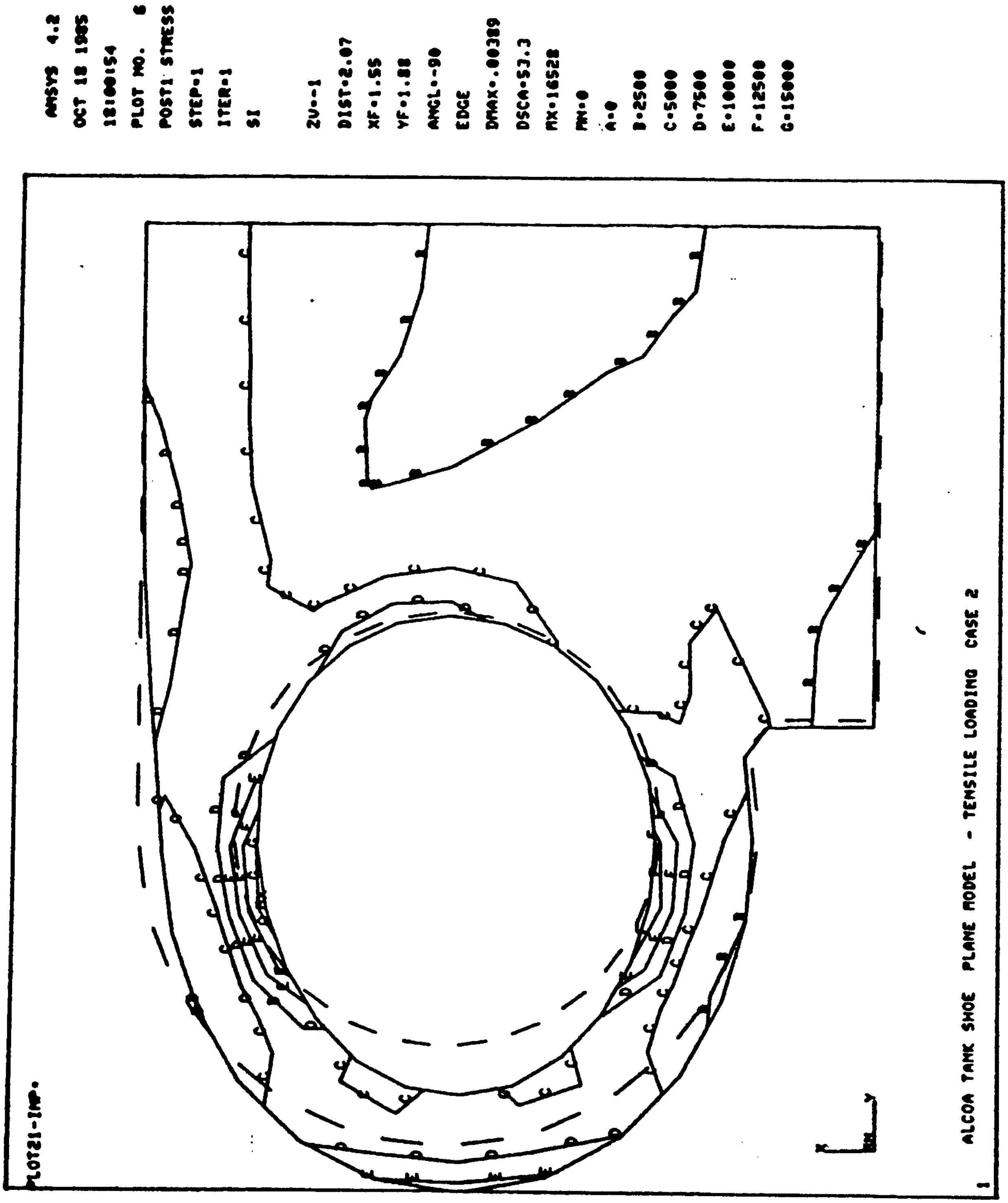


Figure C-11 - Plane Model, Case 2, Stress Intensity

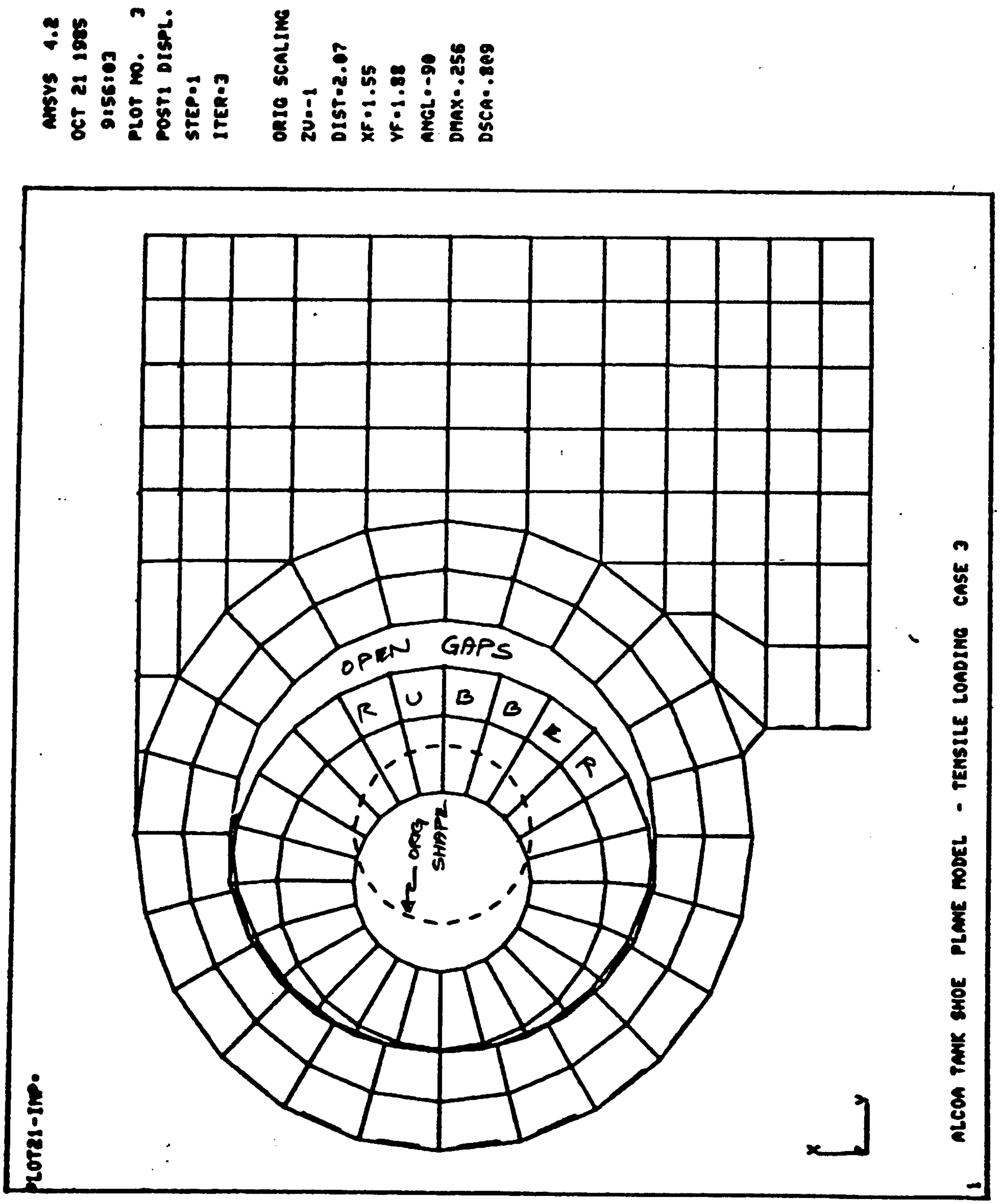


Figure C-12 - Plane Model, Case 3, Displacement Plot

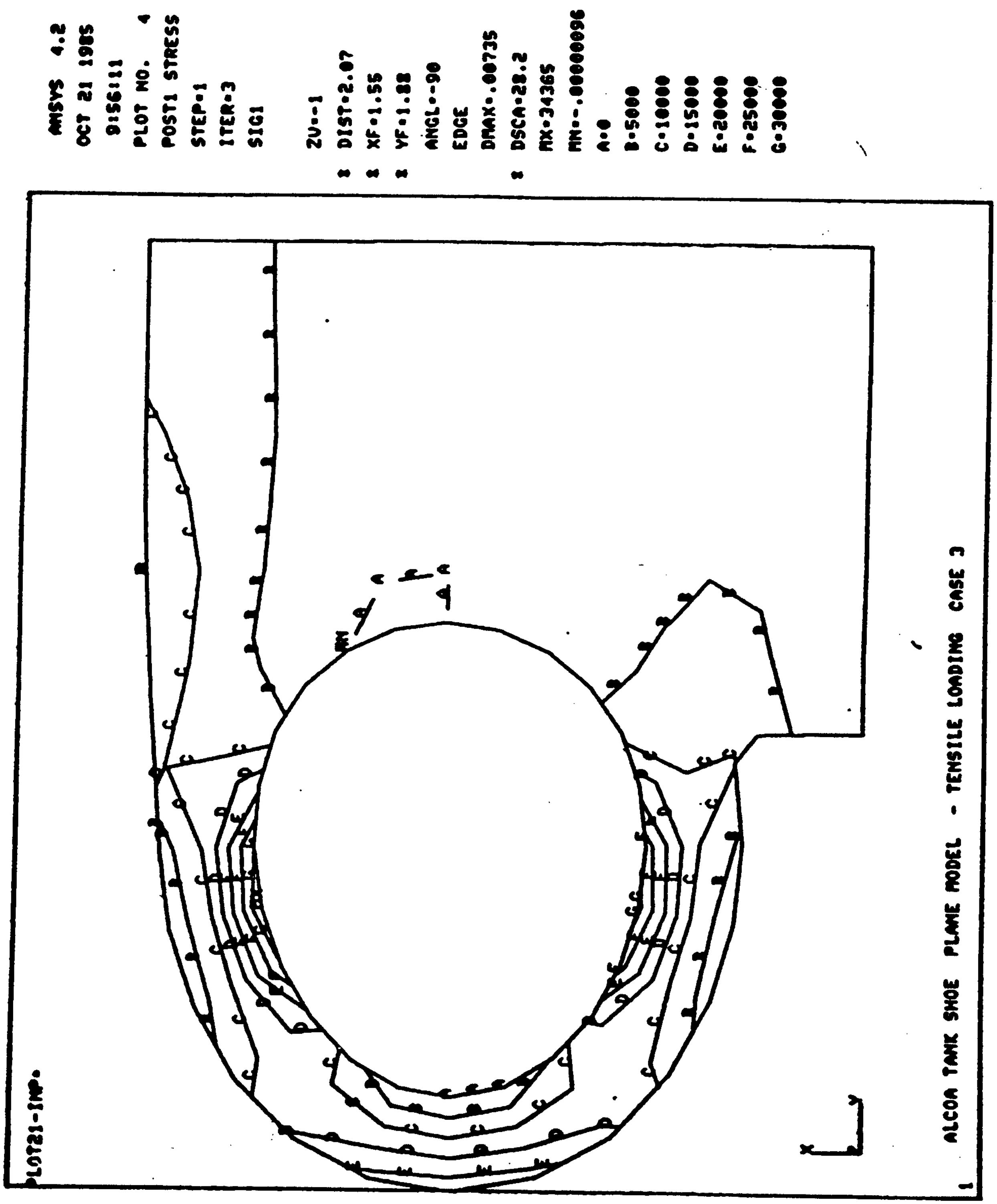


Figure C-13 - Plane Model, Case 3, SIG1 Principal Stress

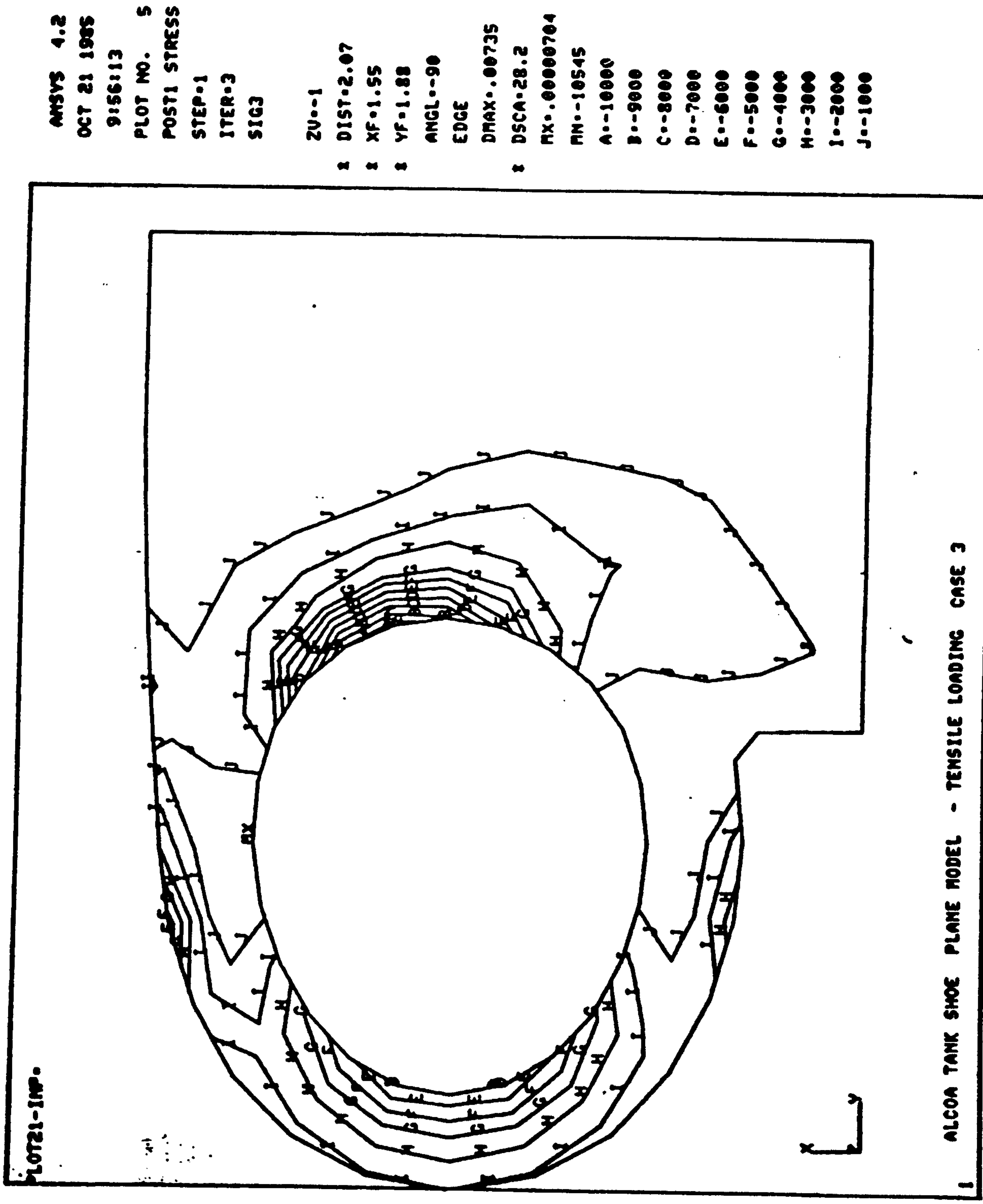


Figure C-14 - Plane Model, Case 3, SIG3 Principal Stress

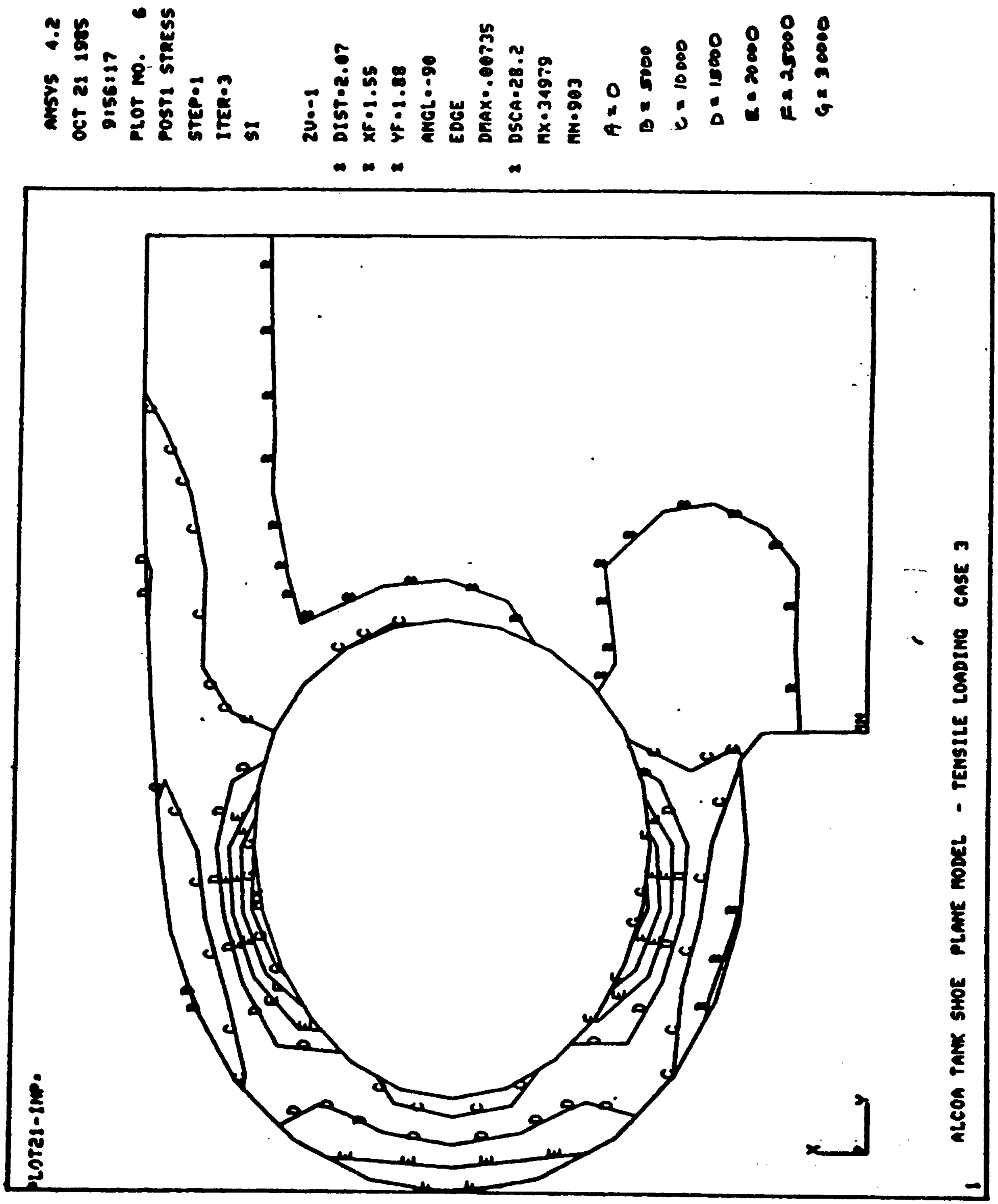


Figure C-15 - Plane Model, Case 3, Stress Intensity

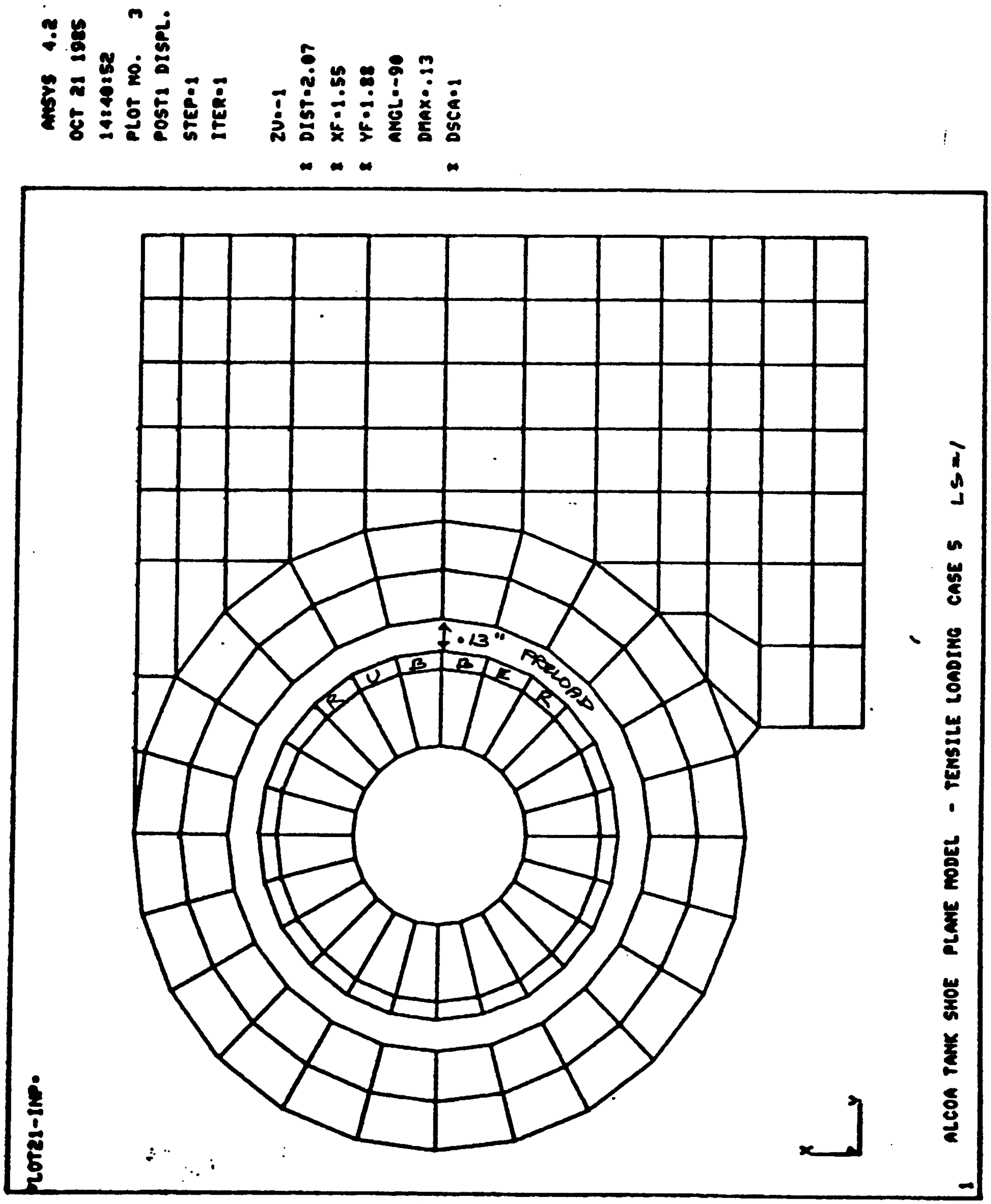


Figure C-16 - Plane Model, Case 5, Preload
Displacement Plot

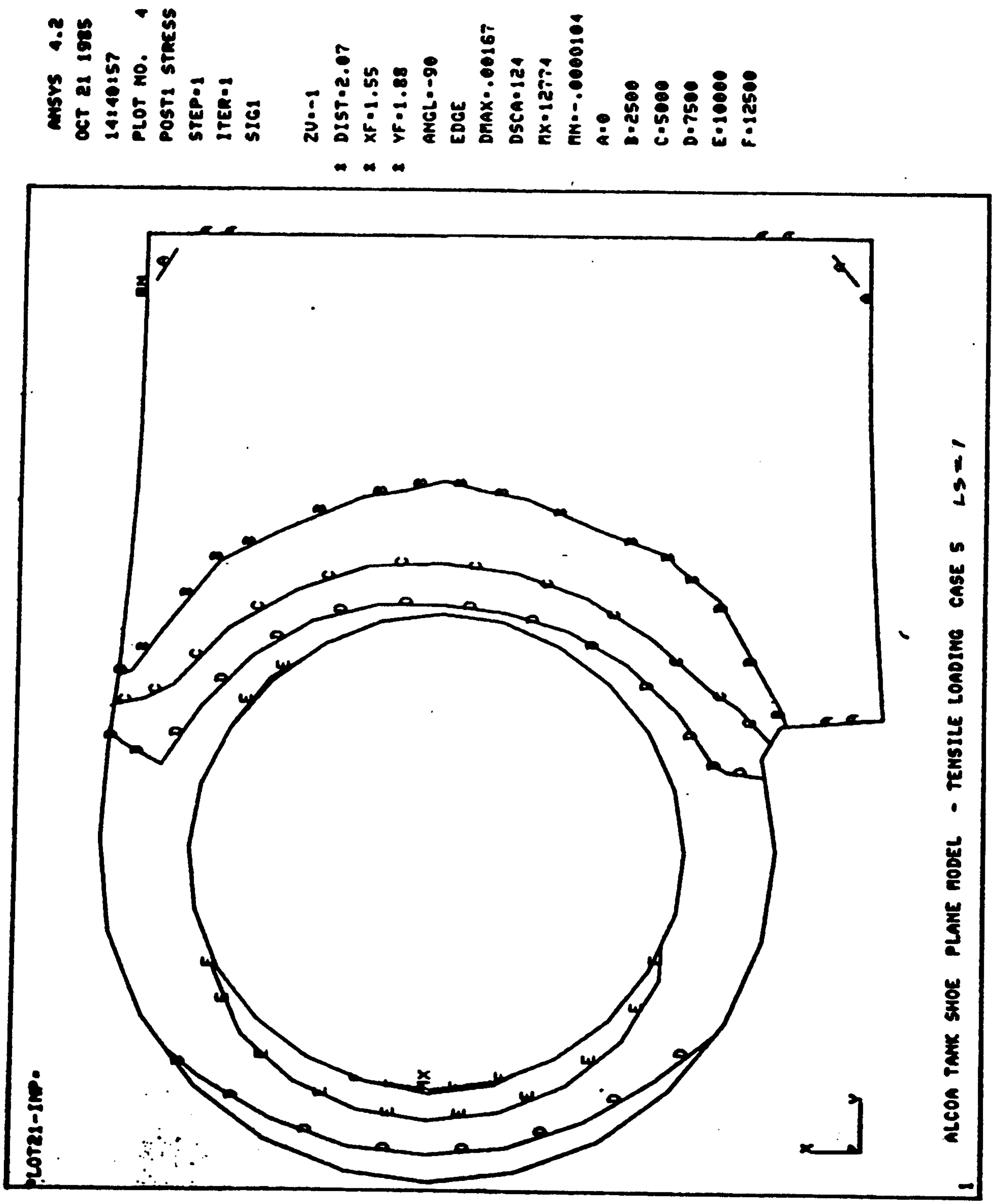


Figure C-17 - Plane Model, Case 5, Preload
SIG1 Principal Stress

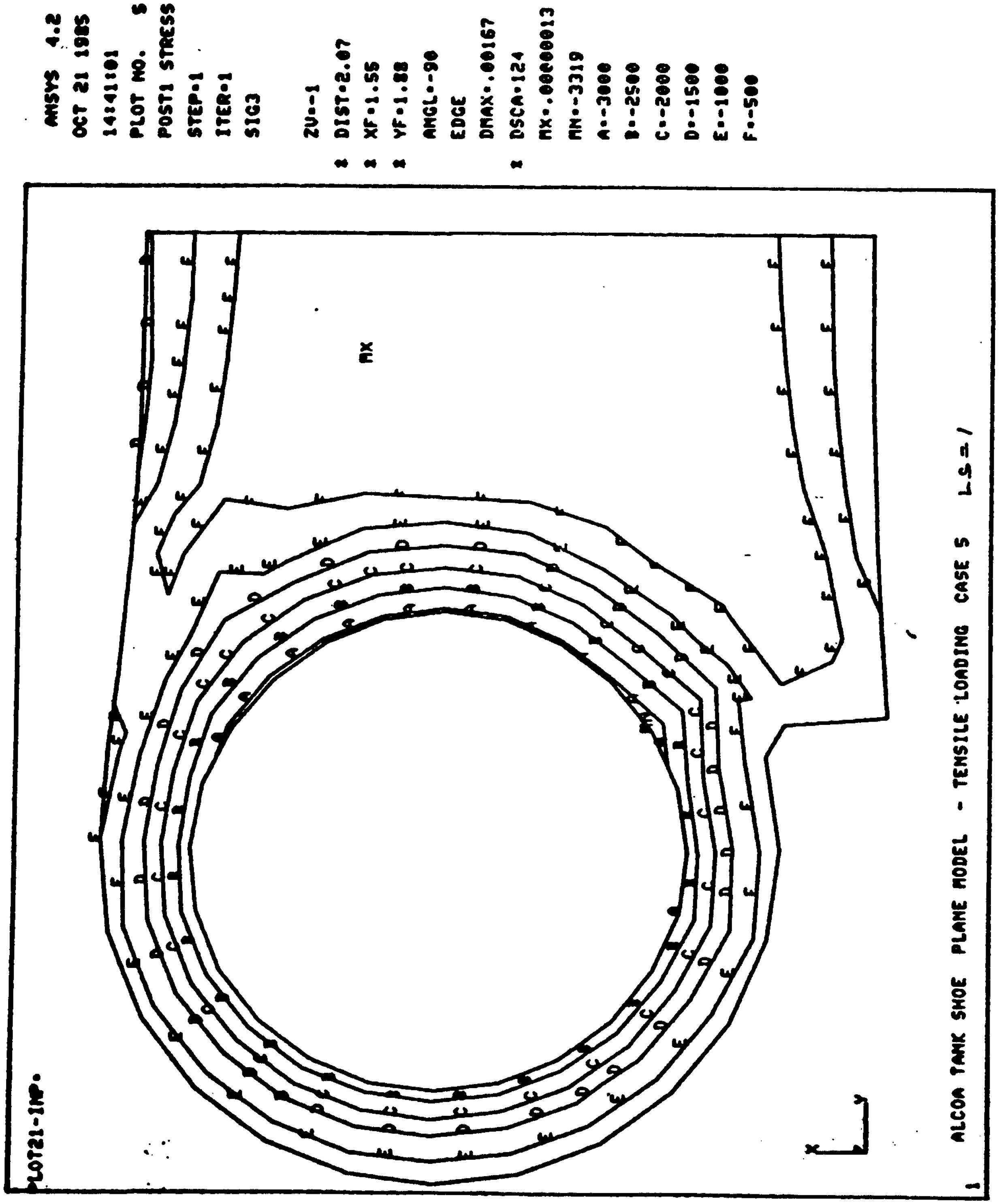


Figure C-18 - Plane Model, Case 5, Preload
SIG3 Principal Stress

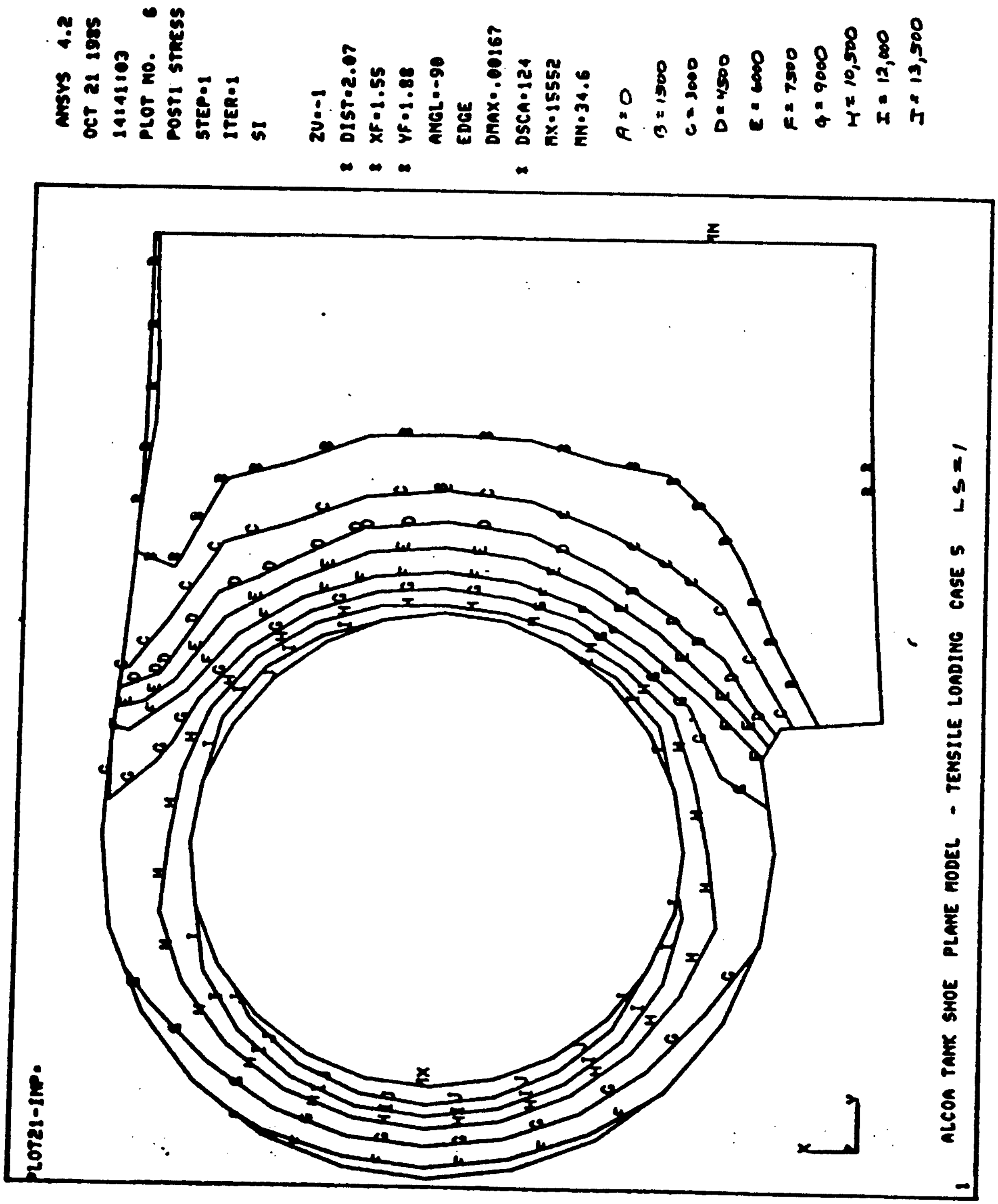


Figure C-19 - Plane Model, Case 5, Preload
Stress Intensity

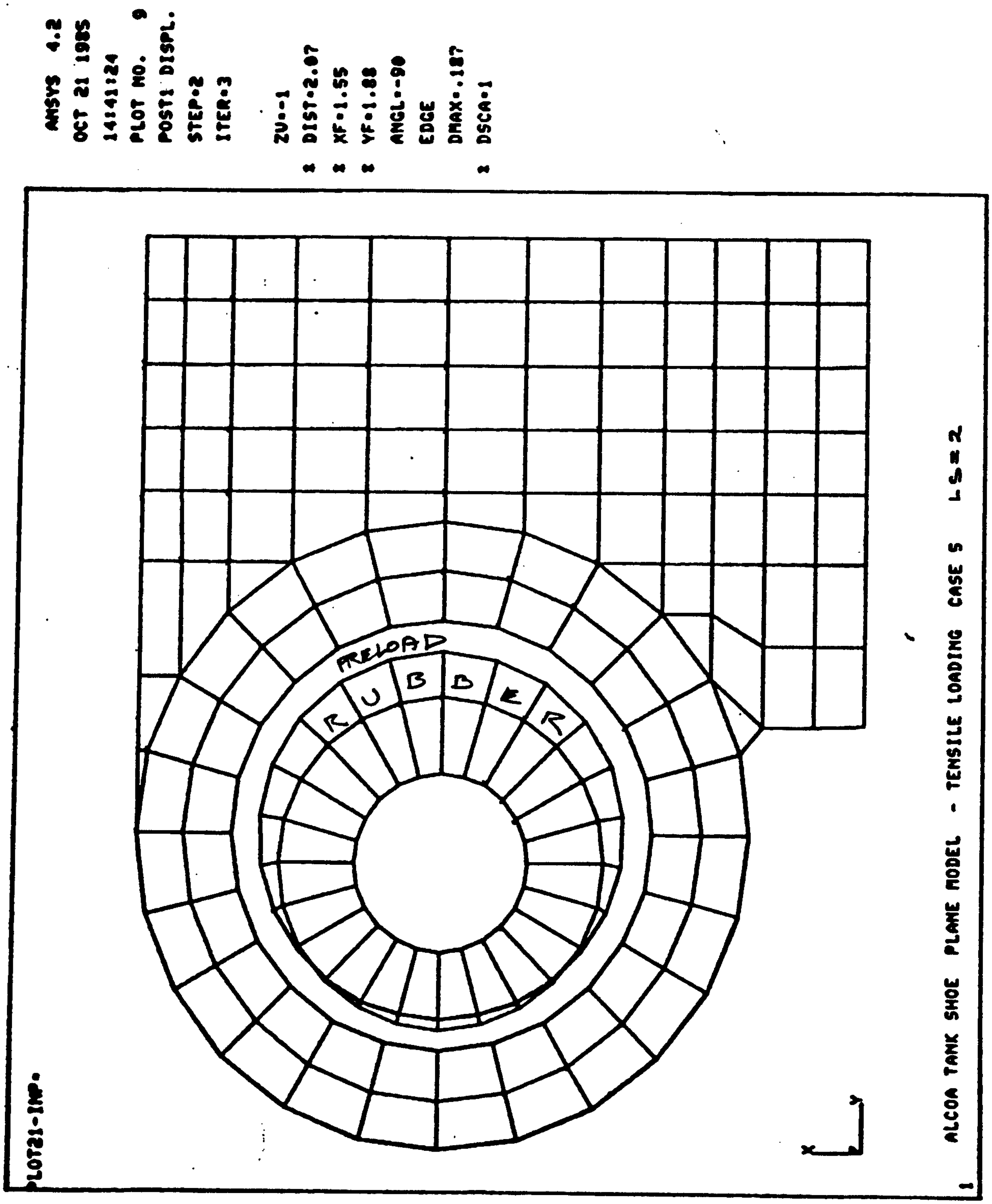


Figure C-20 - Plane Model, Case 5, Preload plus Applied Load
Displacement Plot

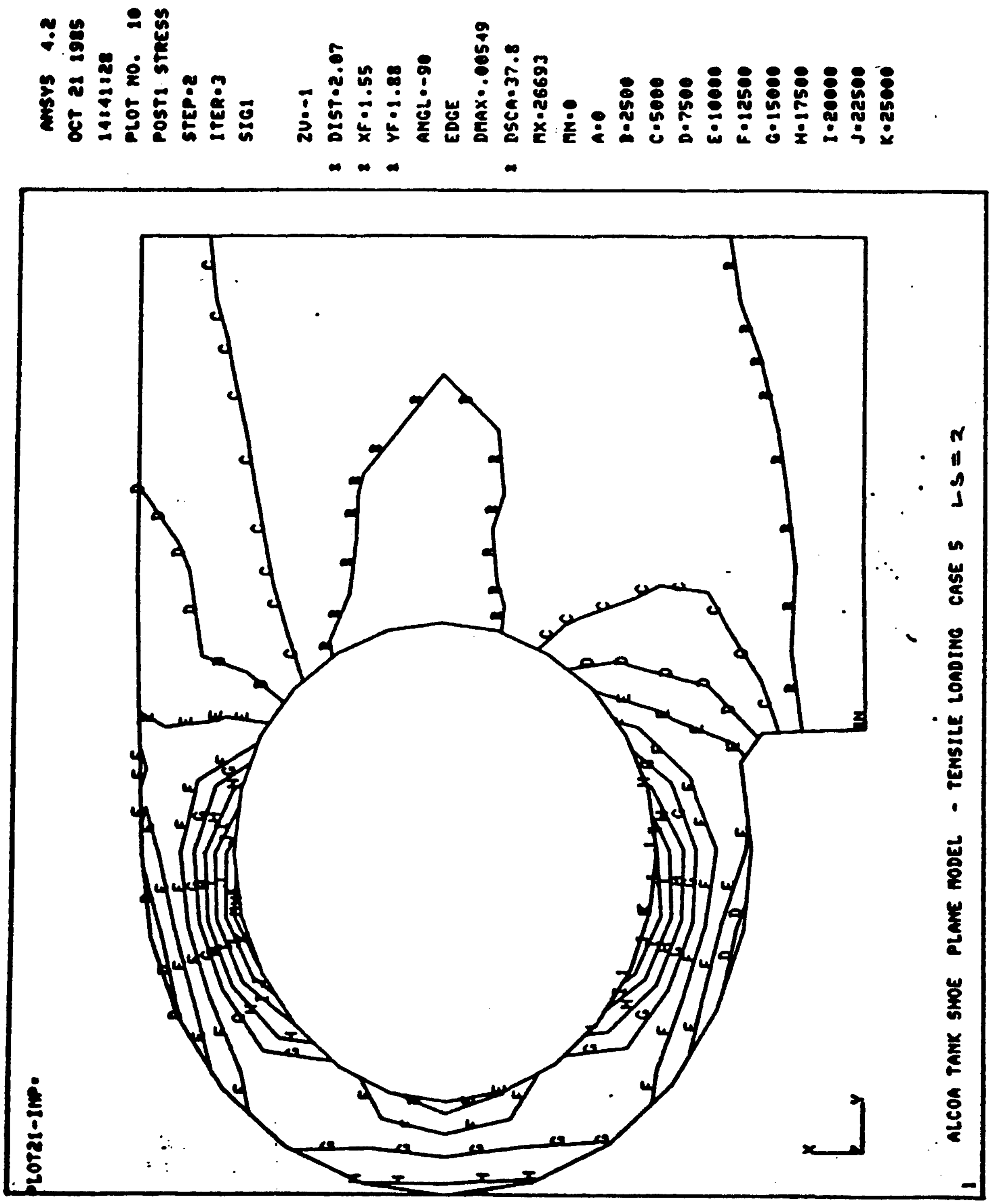


Figure C-21 - Plane Model, Case 5, Preload plus Applied Load
SIG1 Principal Stress

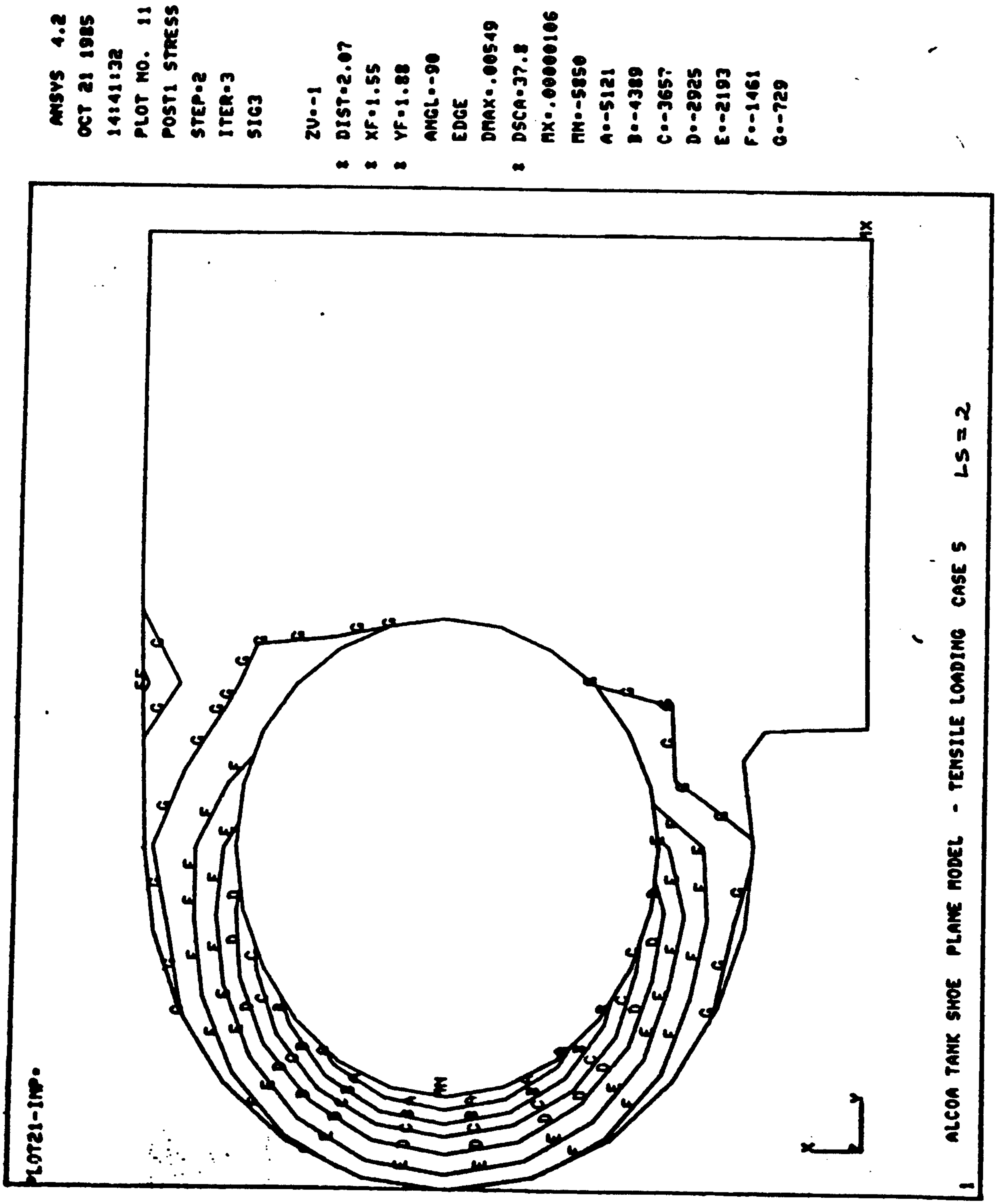


Figure C-22 - Plane Model, Case 5, Preload plus Applied Load
SIG3 Principal Stress

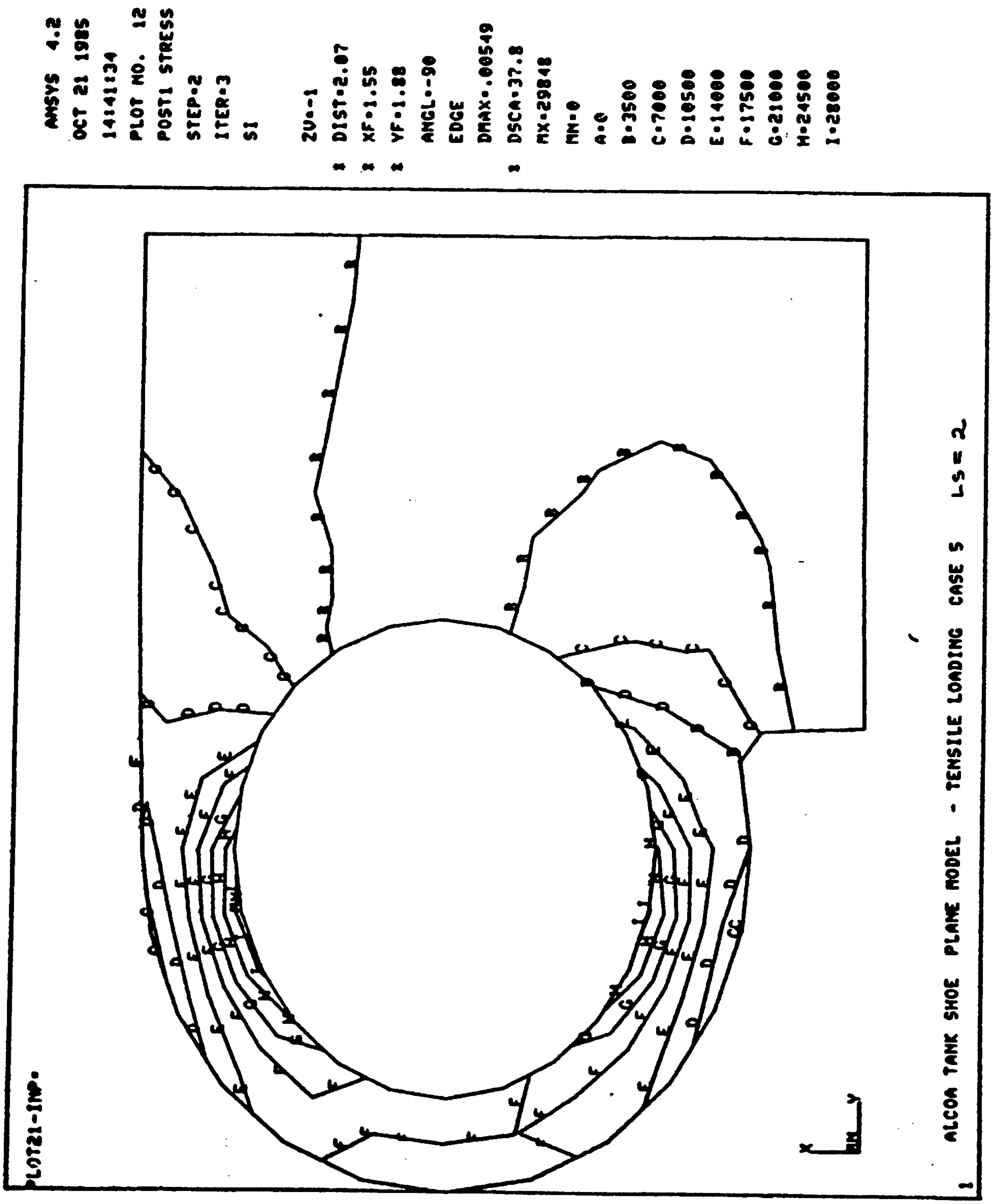


Figure C-23 - Plane Model, Case 5, Preload plus Applied Load Stress Intensity

APPENDIX D

ANSYS 3-D Model

Input Listings

TABLE D-1
ANSYS PREP7 INPUT LISTING FOR
3-D MODEL GENERATION OF M-1 TRACK SHOE

```
/PREP7
/NOPR
/TITLE,  ALCOA TANK SHOE
ET,1,45,.......1          ***  SHAFT
ET,2,45,.......1          ***  RUBBER BUSHING
ET,3,45,.......1          ***  CYLINDER CASTING
ET,4,45,.......1          ***  THICK BACK PLATE
ET,5,45,.......1          ***  WEB & INTERSECTING CYLINDER UAL
ET,6,45,.......1          ***  WEB ONLY
ET,7,45,.......1          ***  FILLETS
C***
C***   SHAFT,RUBBER BUSHING,CASTING CYLINDER    NODES
C***
N,1,1.8,1.3
LOCAL,11,1,1.8,1.3,.25
CSYS,11
N,2,.36875
N,26,.6875
NGEN,24,1,2,26,24,,15.
NGEN,3,150,2,49,1,,,,.4167
LOCAL,12,1,1.8,1.3,1.5
CSYS,12
N,452,.36875
N,476,.6875
N,500,.8905
N,572,1.3
FILL,500,572,1,548
NGEN,24,1,452,476,24,,15.
NGEN,24,1,476,500,24,,15.
NGEN,24,1,500,548,48,,15.
NGEN,24,1,548,572,24,,15.
NGEN,4,150,452,523,1,,,,.319167
NGEN,4,150,548,595,1,,,,.319167
LOCAL,13,1,1.8,1.3,2.5425
CSYS,13
N,1052,.36875
N,1076,.6875
N,1100,.8905
N,1172,1.215
FILL,1100,1172,1,1148
NGEN,24,1,1052,1076,24,,15.
NGEN,24,1,1076,1100,24,,15.
NGEN,24,1,1100,1148,48,,15.
NGEN,24,1,1148,1172,24,,15.
NGEN,3,150,1052,1123,1,,,,.32525
NGEN,3,150,1148,1195,1,,,,.32525
NGEN,2,150,1352,1423,1,,,,.8245
NGEN,2,150,1448,1495,1,,,,.8245
NGEN,7,150,1502,1573,1,,,,.7375
NGEN,7,150,1598,1645,1,,,,.7375
NGEN,2,150,2402,2473,1,,,,.8245
NGEN,2,150,2498,2545,1,,,,.8245
NGEN,3,150,2552,2623,1,,,,.32525
NGEN,3,150,2648,2695,1,,,,.32525
LOCAL,14,1,1.8,1.3,10.0025
CSYS,14
N,3002,.36875
N,3026,.6875
N,3050,.8905
N,3122,1.3
FILL,3050,3122,1,3098
NGEN,24,1,3002,3026,24,,15.
NGEN,24,1,3026,3050,24,,15.
NGEN,24,1,3050,3098,48,,15.
NGEN,24,1,3098,3122,24,,15.
NGEN,4,150,3002,3073,1,,,,.319167
NGEN,4,150,3098,3145,1,,,,.319167
LOCAL,15,1,1.8,1.3,11.2633
CSYS,15
N,3602,.36875
N,3626,.6875
NGEN,24,1,3602,3626,24,,15.
NGEN,3,150,3602,3649,1,,,,.3033
CSYS
NMODIF,1490,,0.
RP9,150
C***
C***  NODES - THICK BACK-PLATE
C***
CSYS
N,4001,3.1,1.6365,1.5
NGEN,4,117,4001,4001,1,,,,.319167
N,4014,3.1,1.95,1.5
NGEN,4,117,4014,4014,1,,,,.319167
N,4027,3.1,2.4258,1.5
N,4028,2.9258,2.4258,1.5
N,4029,2.7192,2.4258,1.5
NGEN,4,117,4027,4029,1,,,,.319167
N,4040,3.1,2.7198,1.5
N,4041,2.9258,2.7198,1.5
N,4042,2.7192,2.7198,1.5
N,4043,2.45,2.7198,1.5
N,4044,2.1365,2.7198,1.5
N,4045,1.80,2.7198,1.5
N,4046,1.4635,2.7198,1.5
N,4047,1.15,2.7198,1.5
N,4048,.88076,2.7198,1.5
NGEN,4,117,4040,4048,1,,,,.319617
NGEN,5,13,4040,4048,1,,.2623
RP4,,,117,117
N,4035,.88076,2.4258,1.5
NGEN,4,117,4035,4035,1,,,,.319167
N,4049,.67417,2.7198,1.5
N,4052,,2.7198,1.5
FILL,4049,4052,2,4050,1
NGEN,3,117,4049,4052,1,,,,.25
NGEN,5,13,4049,4052,1,,.2623
RP3,,,117,117
N,4036,.67417,2.4258,1.5
N,4039,,2.4258,1.5
```

TABLE D-1
(Continued)

```
FILL,4036,4039,2,4037,1
NGEN,3,117,4036,4039,1,,,.25
N,4024,.44945,1.74903,1.5
N,4026,,1.74903,1.5
FILL,4024,4026,1,4025
LOCAL,16,0,,1.74903,1.5,,,-20.8
CSYS,16
NGEN,3,117,4024,4026,1,,,.26743
CSYS
N,4030,.67417,2.2192,1.5
FILL,4024,4037,1,4031
RP3,1,1,,1
NGEN,3,117,4030,4033,1,,,.25
C***
C*** THIN BACK PLATE NODES
C***
N,4618,3.1,1.6356,10.46
N,4631,3.1,1.95,10.46
N,4644,3.1,2.4258,10.46
N,4657,3.1,2.7198,10.46
NGEN,5,13,4657,4657,1,,.2623
NGEN,3,117,4618,4722,13,,,.25
N,4645,2.9258,2.4258,10.46
N,4646,2.7192,2.4258,10.46
NGEN,3,117,4645,4646,1,,,.25
N,4641,.44945,1.93897,10.46
N,4643,,1.93897,10.46
FILL,4641,4643,1,4642
LOCAL,17,0,,1.93897,10.46,,,20.8
CSYS,17
NGEN,3,117,4641,4643,1,,,.26743
CSYS
N,4652,.88076,2.4258,10.46
N,4653,.67417,2.4258,10.46
N,4656,,2.4258,10.46
FILL,4653,4656,2,4654,1
NGEN,3,117,4652,4656,1,,,.25
N,4658,2.9258,2.7198,10.46
N,4659,2.7192,2.7198,10.46
N,4660,2.45,2.7198,10.46
N,4661,2.1365,2.7198,10.46
N,4662,1.8,2.7198,10.46
N,4663,1.4635,2.7198,10.46
N,4664,1.15,2.7198,10.46
N,4665,.88076,2.7198,10.46
N,4666,.67417,2.7198,10.46
N,4669,,2.7198,10.46
FILL,4666,4669,2,4667,1
NGEN,3,117,4658,4669,1,,,.25
NGEN,5,13,4658,4669,1,,.2623
RP3,,,117,117
N,4647,.67417,2.2192,10.46
FILL,4641,4654,1,4648
RP3,1,1,,1
NGEN,3,117,4647,4650,1,,,.25
C***
C***  BOTTOM RIB NODES & CYLINDER INTERSECTION NODES
C***
LOCAL,18,1,,2.224,2.38,,-90,180
CSYS,18
N,5001,1.,48.012
N,5002,.75,48.012
N,5004,1.,67.666
CSYS
N,5006,,1.69571,2.307
N,5018,,.974,3.5
N,5019,,.474,3.5
N,5016,,.57729,3.19296
FILL,5006,5018,3,5009,3
FILL,5004,5016,3,5007,3
FILL,5004,5006,1,5005
RP5,3,3,,3
FILL,5018,5019,1,5020
N,5040,,.474,8.93
N,5042,,.974,8.93
FILL,5019,5040,6,5022,3
FILL,5018,5042,6,5024,3
FILL,5022,5024,1,5023
RP7,3,3,,3
N,5043,,.57729,9.2365
FILL,5042,5043,1,5044
LOCAL,19,1,,2.224,10.05,,-90,180
CSYS,19
N,5058,1.,131.988
N,5059,.75,131.988
N,5055,1.,112.334
CSYS
N,5057,,1.6957,10.1528
FILL,5042,5057,3,5048,3
FILL,5043,5055,3,5046,3
FILL,5046,5048,1,5047
RP4,3,3,,3
NGEN,3,100,5001,5002,1,.224725
NGEN,3,100,5004,5020,1,.224725
NGEN,3,100,5022,5044,1,.224725
NGEN,3,100,5046,5059,1,.224725
NMODIF,5119,,.4148
RP8,3
NMODIF,5219,,.35565
RP8,3
N,5319,.74778,.27709,3.28
NGEN,9,3,5319,5319,1,,,.7375
N,5419,.94087,.22624,3.28
NGEN,9,3,5419,5419,1,,,.7375
N,5519,1.1925,.171,3.28
NGEN,9,3,5519,5519,1,,,.7375
NMODIF,5319,,,3.5
RP3,100
NMODIF,5343,,,8.93
RP3,100
```

TABLE D-1
(Continued)

```
C***
C***  MOVE CYLINDER NODES TO RIB INTERSECTION
C***
C*** THICK SIDE
N,8901,1.9,1.3
N,8902,1.9,1.9
CS,20,1,1,8901,8902
CS,21,0,5016,5001,5113
MOVE,734,20,1.3,999,1.8192,21,999,999,0.
MOVE,884,20,1.3,999,2.1383,21,999,999,0.
MOVE,1035,20,1.3,999,2.4575,21,999,999,0.
MOVE,1185,20,1.215,999,2.5425,21,999,999,0.
MOVE,1336,20,1.215,999,2.86775,21,999,999,0.
MOVE,1486,20,1.215,999,3.193,21,999,999,0.
CS,21,0,5018,4260,5115
MOVE,882,20,1.3,999,2.1383,21,999,999,0.
MOVE,1033,20,1.3,999,2.4575,21,999,999,0.
MOVE,1183,20,1.215,999,2.5425,21,999,999,0.
MOVE,1334,20,1.215,999,2.86775,21,999,999,0.
MOVE,1484,20,1.215,999,3.193,21,999,999,0.
CS,21,0,4260,4026,4259
MOVE,732,20,1.3,999,1.8192,21,999,999,0.
C***
C***  THIN END SIDE MOVE
C***
CSYS
N,3901,1.8,1.3,12.46
N,8801,1.9,1.3,12.46
N,8802,1.9,1.9,12.46
CS,20,1,3901,8801,8802
CS,21,0,5043,5058,5146
MOVE,3434,20,1.3,999,-1.8192,21,999,999,0.
MOVE,3284,20,1.3,999,-2.1383,21,999,999,0.
MOVE,3135,20,1.3,999,-2.4575,21,999,999,0.
MOVE,2985,20,1.215,999,-2.5425,21,999,999,0.
MOVE,2836,20,1.215,999,-2.86775,21,999,999,0.
MOVE,2686,20,1.215,999,-3.193,21,999,999,0.
CS,21,0,5042,4643,5148
MOVE,3282,20,1.3,999,-2.1383,21,999,999,0.
MOVE,3133,20,1.3,999,-2.4575,21,999,999,0.
MOVE,2983,20,1.215,999,-2.5425,21,999,999,0.
MOVE,2834,20,1.215,999,-2.86775,21,999,999,0.
MOVE,2684,20,1.215,999,-3.193,21,999,999,0.
CS,21,0,4643,4877,4642
MOVE,3432,20,1.3,999,-1.8192,21,999,999,0.
C***
C***  RE-DEFINE THE ANGLED SECTION RIB NODES
CSYS
NGEN,2,4516,734,734,1,-.5
RP2,,-2680,2700,2700
FILL,734,5250,1,5150
RP2,2700,20,,20
NGEN,2,4518,733,733,1,-.5443
RP2,,-2680,2700,2700
FILL,733,5251,1,5151
RP2,2700,20,,20
NGEN,2,4368,884,884,1,-.5
RP2,,-2380,2400,2400
FILL,884,5252,1,5152
RP2,2400,20,,20
NGEN,2,4370,883,883,1,-.5443
RP2,,-2380,2400,2400
FILL,883,5253,1,5153
RP2,2400,20,,20
NGEN,2,4372,882,882,1,-.67417
RP2,,-2380,2400,2400
FILL,882,5254,1,5154
RP2,2400,20,,20
NGEN,2,4220,1035,1035,1,-.5443
RP2,,-2080,2100,2100
FILL,1035,5255,1,5155
RP2,2100,20,,20
NGEN,2,4222,1034,1034,1,-.5
RP2,,-2080,2100,2100
FILL,1034,5256,1,5156
RP2,2100,20,,20
NGEN,2,4224,1033,1033,1,-.5443
RP2,,-2080,2100,2100
FILL,1033,5257,1,5157
RP2,2100,20,,20
NGEN,2,4073,1185,1185,1,-.5443
RP2,,-1780,1800,1800
FILL,1185,5258,2,5058,100
RP2,1800,20,,20
NGEN,2,4075,1184,1184,1,-.5
RP2,,-1780,1800,1800
FILL,1184,5259,2,5059,100
RP2,1800,20,,20
NGEN,2,4077,1183,1183,1,-.5443
RP2,,-1780,1800,1800
FILL,1183,5260,2,5060,100
RP2,1800,20,,20
NGEN,2,3925,1336,1336,1,-.67417
RP2,,-1480,1500,1500
FILL,1336,5261,2,5061,100
RP2,1500,20,,20
NGEN,2,3927,1335,1335,1,-.5443
RP2,,-1480,1500,1500
FILL,1335,5262,2,5062,100
RP2,1500,20,,20
NGEN,2,3929,1334,1334,1,-.5
RP2,,-1480,1500,1500
FILL,1334,5263,2,5063,100
RP2,1500,20,,20
NGEN,2,3778,1486,1486,1,-.67417
RP2,,-1180,1200,1200
FILL,1486,5264,2,5064,100
RP2,1200,20,,20
NGEN,2,3780,1485,1485,1,-.5443
RP2,,-1180,1200,1200
```

TABLE D-1
(Continued)

```
FILL,1485,5265,2,5065,100
RP2,1200,20,,20
NGEN,2,3782,1484,1484,1,-.5
RP2,,-1180,1200,1200
FILL,1484,5266,2,5066,100
RP2,1200,20,,20
C***
C***  MOVE CYLINDER TO MATCH WEB BOTTOM
C***
CSYS
LOCAL,22,1,.74,3.769,3.852,,90,180
CSYS,22
N,6001,.43,180,0.
NGEN,13,1,6001,6001,1,,-15.
NGEN,3,13,6001,6013,1,.315
CSYS
CS,20,1,1,8901,8902
CS,21,0,6001,6013,6012
MOVE,1181,20,1.215,999,2.5425,21,999,999,0.
RP3,150,,,,.32525
MOVE,1631,20,1.215,999,4.0175,21,999,999,0.
RP7,150,,,,.7375
MOVE,2681,20,1.215,999,9.267,21,999,999,0.
RP3,150,,,,.32525
MOVE,3131,20,1.215,999,9.96,21,999,999,0.
CSYS
NGEN,2,200,6001,6039,1,.31
NGEN,2,200,6201,6239,1,.13
NGEN,2,200,6401,6439,1,.12
NMODIF,4451,0.74
RP6,-13
NMODIF,4717,0.74
RP6,-13
C***
C***  MOVE CYLINDER TANGENT TO MEET WEB
CSYS
CS,20,1,1,8901,8902
CS,21,0,6201,6213,6212
MOVE,1180,20,1.215,999,2.5425,21,999,999,0.
RP3,150,,,,.32525
MOVE,1630,20,1.215,999,4.0175,21,999,999,0.
RP7,150,,,,.7375
MOVE,2680,20,1.215,999,9.267,21,999,999,0.
RP3,150,,,,.32525
MOVE,3130,20,1.215,999,9.96,21,999,999,0.
C***
C***  MOVE BACK PLATES
CSYS
NMODIF,4450,1.05
RP5,-13
NMODIF,4716,1.05
RP5,-13
NMODIF,5250,9.E-8
RP17,1
NMODIF,5270,9.E-8
RP17,1
C***
C***  WEB NODES
CSYS
NMODIF,6037,,,4.755
RP3,1
NMODIF,6237,,,4.755
RP3,1
NGEN,2,4936,1180,1180,1,-.31
RP14,,-149,150,150
NGEN,2,1589,4451,4451,1,,,,.085
RP5,,14,-13,-13
FILL,6043,6030,1,6045
FILL,6031,6117,1,6046
FILL,6032,6118,1,6047
FILL,6034,6120,1,6050
FILL,6047,6050,1,6049,1
NDELETE,6050
NGEN,3,4132,1930,1930,1,,.147
RP9,,-144,150,150
NGEN,2,1,6062,6110,6,,.147
NGEN,5,1,6063,6111,6,,.2623
N,6051,.74,2.5728,4.755
N,6052,.74,2.5499,5.005
N,6061,.74,3.769,4.855
N,6054,.74,2.7451,4.855
N,6056,.74,2.851,4.855
FILL,6056,6061,3,6058,1
N,6055,.74,2.851,4.755
N,6057,.74,3.0195,4.755
N,6053,.74,2.7451,4.755
NMODIF,6062,.74
RP54,1
NMODIF,6046,,2.5236
NMODIF,6047,,2.5236
RP3,2
NGEN,2,200,6040,6115,1,.31
NGEN,2,200,6240,6251,1,.13
NGEN,2,200,6253,6257,2,.13
NGEN,2,200,6440,6451,1,.12
NGEN,2,200,6453,6457,2,.12
NMODIF,6437,,,4.755
RP3,1
NMODIF,6637,,,4.755
RP3,1
NMODIF,6067,,3.769
RP9,6
NMODIF,6267,,3.769
RP9,6
NMODIF,6627,1.42
NMODIF,6640,1.42
NMODIF,6628,1.36
NMODIF,6641,1.36
NMODIF,6632,1.36
NMODIF,6647,1.36
```

TABLE D-1
(Continued)

```
NMODIF,6633,1.42
NMODIF,6634,1.47
NMODIF,6635,1.53
NMODIF,6636,1.47
NMODIF,6640,1.3818
RP5,1
NMODIF,6649,1.42
NMODIF,6651,1.64,,4.6015
NMODIF,6653,1.6,,4.6322
NMODIF,6655,1.53,,4.6629
NMODIF,6657,1.465,,4.6936
C***
C***  FILLET NODES AND MODIFICATIONS
C***
CS,25,1,3901,8801,8802
CSYS,25
NMODIF,3123,1.249,,-2.3405
RP7,1
CS,25,1,1,8901,8902
CSYS,25
NMODIF,1173,1.249,,2.705125
RP6,1
CSYS,0
NMODIF,6104,,,9.9175
RP2,200
NMODIF,6110,,,10.119
RP2,200
NMODIF,6105,,2.7198,9.9175
RP2,200
NMODIF,6106,,2.9821,9.9175
RP2,200
NMODIF,6107,,3.244,9.9175
RP2,200
NMODIF,6108,,3.5067,9.9175
RP2,200
NMODIF,6109,,3.769,9.9175
RP2,200
NMODIF,6111,,2.7198,10.119
RP2,200
NMODIF,6112,,2.9821,10.119
RP2,200
NMODIF,6113,,3.244,10.119
RP2,200
NMODIF,6114,,3.5067,10.119
RP2,200
NMODIF,6115,,3.769,10.119
RP2,200
FILL,1929,6263,1,7001,1
RP9,150,6,,1
FILL,4663,6305,1,7015,1
RP5,13,1,,1
FILL,3279,6304,1,7014
NMODIF,7015,1.20
RP5,1
NMODIF,6052,,,4.97375
RP2,200
NMODIF,6054,,,4.97375
RP2,200
NMODIF,6056,,,4.97375
RP2,200
NMODIF,6058,,,4.97375
RP2,200
NMODIF,6059,,,4.97375
RP3,1
NMODIF,6259,,,4.97375
RP3,1
NMODIF,1779,1.7
NMODIF,1778,1.92
NMODIF,1629,1.6
NMODIF,4337,,,2.0602
RP7,-13
NMODIF,4336,,,2.12043
RP7,-13
NMODIF,4335,,,2.18064
RP6,-13
NMODIF,4720,,,10.3998
RP7,-13
NMODIF,4719,,,10.33957
RP7,-13
NMODIF,4718,,,10.27936
RP6,-13
NMODIF,4717,,,10.26172
RP6,-13
NMODIF,5118,,1.03422
NMODIF,5218,,1.09443
NMODIF,5124,,1.03422
RP7,3
NMODIF,5224,,1.09443
RP7,3
NMODIF,1485,,1.15337
RP9,150
CS,20,0,5254,5257,5154
NMODIF,5154,,,.07262
RP5,3
NMODIF,5060,,,.115604
RP3,3
NMODIF,882,,,.16294
NMODIF,1033,,,.14450
NMODIF,1183,,,.16422
NMODIF,1334,,,.15704
NMODIF,1484,,,.15954
CS,20,0,5274,5174,5277
NMODIF,5174,,,.07262
RP5,3
NMODIF,5080,,,.115604
RP3,3
NMODIF,3282,,,.16294
NMODIF,3133,,,.14450
NMODIF,2983,,,.16422
NMODIF,2834,,,.15704
```

TABLE D-1
(Continued)

```
E,3275,4646,3276,3276,3425,4763,3426,3426
RP2,150,117,150,150,150,117,150,150
E,4646,4659,4660,3276,4763,4776,4777,3426
RP2,117,117,117,150,117,117,117,150
E,3276,4660,4661,3277,3426,4777,4778,3427
RP2,150,117,117,150,150,117,117,150
EGEN,4,1,-2
E,3280,4652,3281,3281,3430,4769,3431,3431
RP2,150,117,150,150,150,117,150,150
E,3280,4664,4665,4652,3430,4781,4782,4769
RP2,150,117,117,117,150,117,117,117
E,3281,4652,4653,4647,3431,4769,4770,4764
RP2,150,117,117,117,150,117,117,117
E,3281,4647,3282,3282,3431,4764,3432,3432
RP2,150,117,150,150,150,117,150,150
E,3282,4641,3283,3283,3432,4758,3433,3433
RP2,150,117,150,150,150,117,150,150
E,3282,4647,4648,4641,3432,4764,4765,4758
RP2,150,117,117,117,150,117,117,117
E,4647,4653,4654,4648,4764,4770,4771,4765
EGEN,2,117,-1
EGEN,3,1,-2
E,4644,4657,4658,4645,4761,4774,4775,4762
EGEN,2,117,-1
EGEN,2,1,-2
E,4652,4665,4666,4653,4769,4782,4783,4770
EGEN,2,117,-1
EGEN,4,1,-2
E,4641,4648,4649,4642,4758,4765,4766,4759
EGEN,2,117,-1
EGEN,2,1,-2
E,4657,4670,4671,4658,4774,4787,4788,4775
EGEN,2,117,-1
EGEN,4,13,-2
EGEN,12,1,-8
C***
C***  RIB & INTERSECTING CYLINDER WALL ELEM'S
C***
TYPE,5
MAT,3
E,5022,5019,5020,5023,5122,5119,5120,5123
EGEN,7,3,-1
EGEN,2,100,-7
E,5024,5018,5020,5023,5124,5118,5120,5123
E,5027,5024,5023,5026,5127,5124,5123,5126
EGEN,6,3,-1
EGEN,2,100,-7
E,5319,5219,5322,5322,1486,5220,1636,1636
RP2,24,21,18,18,1200,21,900,900
E,1486,5220,1636,1636,1485,5218,1635,1635
RP2,1200,21,900,900,1200,24,900,900
E,5219,5222,5322,5322,5220,5223,1636,1636
E,5220,5223,1636,1636,5218,5224,1635,1635
E,5222,5225,5325,5325,5223,5226,1786,1786
RP6,3,3,3,3,3,3,150,150
E,5223,5226,1786,1786,5224,5227,1785,1785
RP6,3,3,150,150,3,3,150,150
E,5322,5325,5222,5222,1636,1786,5223,5223
RP6,3,3,3,3,150,150,3,3
E,1636,1786,5223,5223,1635,1785,5224,5224
RP6,150,150,3,3,150,150,3,3
E,5319,5322,1636,1486,5419,5422,1637,1487
RP8,3,3,150,150,3,3,150,150
E,5419,5422,1637,1487,5519,5522,1638,1488
RP8,3,3,150,150,3,3,150,150
E,5519,1488,1489,1489,5522,1638,1639,1639
RP8,3,150,150,150,3,150,150,150
C***
C***  RIB ELEMS - ANGLED SECTION
C***
E,5157,5154,5153,5153,1033,882,883,883
RP2,20,20,20,20,2100,2400,2400,2400
E,4025,5150,5151,5151,4024,734,733,733
RP2,851,20,20,20,851,2700,2700,2700
E,4026,5250,5251,5251,4025,5150,5151,5151
RP2,851,20,20,20,851,20,20,20
E,4025,5151,4142,4142,4024,733,4141,4141
RP2,851,20,617,617,851,2700,617,617
E,4026,5251,4143,4143,4025,5151,4142,4142
RP2,851,20,617,617,851,20,617,617
E,4142,5151,5153,5154,4141,733,883,882
RP2,617,20,20,20,617,2700,2400,2400
E,4143,5251,5253,5254,4142,5151,5153,5154
RP2,617,20,20,20,617,20,20,20
E,5154,4259,4142,4142,882,4258,4141,4141
RP2,20,383,617,617,2400,383,617,617
E,5254,4260,4143,4143,5154,4259,4142,4142
RP2,20,383,617,617,20,383,617,617
E,5019,5264,5265,5020,5119,5164,5165,5120
RP2,21,20,20,21,21,20,20,21
E,5020,5265,5266,5018,5120,5165,5166,5118
RP2,21,20,20,24,21,20,20,24
E,5119,5164,5165,5120,5219,5064,5065,5220
RP2,21,20,20,21,21,20,20,21
E,5120,5165,5166,5118,5220,5065,5066,5218
RP2,21,20,20,24,21,20,20,24
E,5150,5152,5153,5151,734,884,883,733
RP2,20,20,20,20,2700,2400,2400,2700
E,5152,5155,5156,5156,884,1035,1034,1034
RP2,20,20,20,20,2400,2100,2100,2100
E,5152,5156,5157,5153,884,1034,1033,883
RP2,20,20,20,20,2400,2100,2100,2400
E,5155,5058,5059,5156,1035,1185,1184,1034
RP2,20,20,20,20,2100,1800,1800,2100
E,5156,5059,5060,5157,1034,1184,1183,1033
RP2,20,20,20,20,2100,1800,1800,2100
E,5058,5158,5155,5155,5059,5159,5156,5156
E,5059,5159,5156,5156,5060,5160,5157,5157
EGEN,2,20,-2
E,5058,5061,5062,5062,1185,1336,1335,1335
```

TABLE D-1
(Continued)

```
MMODIF,2684,,,.15954
CSYS
MMODIF,3902,,,11.87
RP48,1
MMODIF,1485,.58
RP9,150
C***
C***  SHAFT ELEMENTS
C***
TYPE,1
MAT,1
E,199,49,25,175,176,26,2,152
E,176,26,2,152,177,27,3,153
EGEN,23,1,-1
EGEN,26,150,-24
C***
C***  RUBBER BUSHING ELEMENTS
C***
TYPE,2
MAT,2
E,673,523,499,649,650,500,476,626
E,650,500,476,626,651,501,477,627
EGEN,23,1,-1
EGEN,20,150,-24
C***
C***  CASTING CYLINDER ELEMENTS
C***
TYPE,3
MAT,3
E,745,595,571,721,722,572,548,698
E,721,571,523,673,698,548,500,650
E,722,572,548,698,723,573,549,699
E,698,548,500,650,699,549,501,651
EGEN,23,1,-2
EGEN,20,150,-48
C***
C***  THICK BACK-PLATE ELEMENTS
C***
TYPE,4
MAT,3
E,572,4001,573,573,722,4118,723,723
RP3,150,117,150,150,150,117,150,150
E,4001,4014,574,573,4118,4131,724,723
RP3,117,117,150,150,117,117,150,150
E,574,4028,4029,575,724,4145,4146,725
RP3,150,117,117,150,150,117,117,150
E,575,4029,576,576,725,4146,726,726
RP3,150,117,150,150,150,117,150,150
E,576,4043,4044,577,726,4160,4161,727
RP3,150,117,117,150,150,117,117,150
E,577,4044,4045,578,727,4161,4162,728
RP3,150,117,117,150,150,117,117,150
E,578,4045,4046,579,728,4162,4163,729
RP3,150,117,117,150,150,117,117,150
E,579,4046,4047,580,729,4163,4164,730
RP3,150,117,117,150,150,117,117,150
E,580,4035,581,581,730,4152,731,731
RP3,150,117,150,150,150,117,150,150
E,581,4030,582,582,731,4147,732,732
RP2,150,117,150,150,150,117,150,150
E,581,4035,4036,4030,731,4152,4153,4147
RP2,150,117,117,117,150,117,117,117
E,881,1031,4264,4264,4269,4386,4270,4270
E,882,1031,881,881,4264,4264,4264,4264
E,582,4024,583,583,732,4141,733,733
RP2,150,117,150,150,150,117,150,150
E,4014,4027,4028,574,4131,4144,4145,724
RP3,117,117,117,150,117,117,117,150
E,4027,4040,4041,4028,4144,4157,4158,4145
EGEN,3,117,-1
EGEN,2,1,-3
E,4029,4042,4043,576,4146,4159,4160,726
RP3,117,117,117,150,117,117,117,150
E,580,4047,4048,4035,730,4164,4165,4152
RP3,150,117,117,117,150,117,117,117
E,4035,4048,4049,4036,4152,4165,4166,4153
EGEN,2,117,-1
EGEN,5,13,-2
E,4269,4386,4270,4270,4282,4399,4283,4283
EGEN,5,13,-1
E,582,4030,4031,4024,732,4147,4148,4141
RP2,150,117,117,117,150,117,117,117
E,4030,4036,4037,4031,4147,4153,4154,4148
EGEN,2,117,-1
EGEN,3,1,-2
E,4024,4031,4032,4025,4141,4148,4149,4142
EGEN,2,117,-1
EGEN,2,1,-2
E,4036,4049,4050,4037,4153,4166,4167,4154
EGEN,2,117,-1
EGEN,3,1,-2
E,4040,4053,4054,4041,4157,4170,4171,4158
EGEN,3,117,-1
EGEN,4,13,-3
EGEN,8,1,-12
E,4049,4062,4063,4050,4166,4179,4180,4167
EGEN,2,117,-1
EGEN,4,13,-2
EGEN,3,1,-8
C***
C***  THIN BACK PLATE ELEMENTS
C***
E,3272,4618,3273,3273,3422,4735,3423,3423
RP2,150,117,150,150,150,117,150,150
E,4618,4631,3274,3273,4735,4748,3424,3423
RP2,117,117,150,150,117,117,150,150
E,4631,4644,4645,3274,4748,4761,4762,3424
RP2,117,117,117,150,117,117,117,150
E,3274,4645,4646,3275,3424,4762,4763,3425
RP2,150,117,117,150,150,117,117,150
```

TABLE D-1
(Continued)

```
RP2,20,20,20,20,1800,1500,1500,1500
E,5058,5062,5063,5059,1185,1335,1334,1184
RP2,20,20,20,20,1800,1500,1500,1800
E,5059,5063,5060,5060,1184,1334,1183,1183
RP2,20,20,20,20,1800,1500,1800,1800
E,5061,5064,5065,5062,1336,1486,1485,1335
RP2,20,20,20,20,1500,1200,1200,1500
E,5062,5065,5066,5063,1335,1485,1484,1334
RP2,20,20,20,20,1500,1200,1200,1500
E,5257,5254,5253,5253,5157,5154,5153,5153
E,5250,5252,5253,5251,5150,5152,5153,5151
E,5252,5255,5256,5256,5152,5155,5156,5156
E,5252,5256,5257,5253,5152,5156,5157,5153
E,5255,5258,5259,5256,5155,5158,5159,5156
E,5256,5259,5260,5257,5156,5159,5160,5157
E,5158,5161,5162,5162,5058,5061,5062,5062
E,5158,5162,5163,5159,5058,5062,5063,5059
E,5159,5163,5160,5160,5059,5063,5060,5060
E,5161,5164,5165,5162,5061,5064,5065,5062
E,5162,5165,5166,5163,5062,5065,5066,5063
EGEN,2,100,-5
EGEN,2,20,-16
E,1486,5064,5219,5219,1485,5065,5220,5220
RP2,1200,20,24,24,1200,20,24,24
E,5218,5220,5065,5065,1485,1485,1485,1485
RP2,24,24,20,20,1200,1200,1200,1200
E,1484,5066,5218,5218,5065,5065,5065,5065
RP2,1200,20,24,24,20,20,20,20
E,1485,1484,5218,5218,5065,5065,5065,5065
RP2,1200,1200,24,24,20,20,20,20
C***
C***  WEB ELEMS
C***
TYPE,6
MAT,3
E,6001,6014,6015,6002,6201,6214,6215,6202
EGEN,2,13,-1
EGEN,12,1,-2
EGEN,2,200,-24
E,4386,1031,1030,1030,6116,1181,1180,1180
E,6116,1181,1180,1180,6117,1331,1330,1330
RP13,1,150,150,150,1,150,150,150
E,6129,3131,3130,3130,4652,3281,3280,3280
E,4451,6040,6041,4438,4450,6240,6241,4437
RP4,-13,1,1,-13,-13,1,1,-13
E,4399,6044,6116,4386,4398,6244,1180,1030
E,6040,6027,6028,6041,6240,6227,6228,6241
EGEN,2,1,-1
E,6042,6029,6045,6043,6242,6229,6245,6243
E,6029,6030,6045,6045,6229,6230,6245,6245
E,6045,6030,6031,6044,6245,6230,6231,6244
E,6031,6046,6044,6044,6231,6246,6244,6244
E,6043,6045,6044,6044,6243,6245,6244,6244
EGEN,3,200,-7
E,6044,6046,6117,6116,6244,6246,1330,1180
E,6031,6032,6047,6046,6231,6232,6247,6246
EGEN,3,200,-1
E,6046,6047,6118,6117,6246,6247,1480,1330
E,6032,6033,6049,6047,6232,6233,6249,6247
E,6033,6034,6049,6049,6233,6234,6249,6249
E,6034,6053,6051,6049,6234,6253,6251,6249
EGEN,3,200,-3
E,6047,6049,6119,6118,6247,6249,1630,1480
E,6049,6051,6120,6119,6249,6251,1780,1630
E,6051,6052,6120,6120,6251,6252,1780,1780
E,6053,6054,6052,6051,6253,6254,6252,6251
E,6052,6062,6121,6120,6252,6262,1930,1780
E,6052,6062,6063,6063,6252,6262,6263,6263
E,6054,6052,6063,6063,6254,6252,6263,6263
E,6035,6055,6053,6034,6235,6255,6253,6234
EGEN,3,200,-1
E,6055,6056,6054,6053,6255,6256,6254,6253
E,6054,6063,6064,6064,6254,6263,6264,6264
E,6054,6056,6064,6064,6254,6256,6264,6264
E,6036,6057,6055,6035,6236,6257,6255,6235
EGEN,3,200,-1
E,6057,6058,6056,6055,6257,6258,6256,6255
E,6058,6064,6056,6056,6258,6264,6256,6256
E,6036,6057,6037,6037,6236,6257,6237,6237
EGEN,3,200,-1
E,6037,6059,6058,6057,6237,6259,6258,6257
E,6059,6065,6064,6058,6259,6265,6264,6258
EGEN,2,1,-1
E,6060,6066,6067,6067,6260,6266,6267,6267
E,6060,6067,6061,6061,6260,6267,6261,6261
E,6038,6060,6059,6037,6238,6260,6259,6237
EGEN,2,1,-1
E,6062,6068,6122,6121,6262,6268,2080,1930
RP7,6,6,1,1,6,6,150,150
E,6104,6110,6129,6128,6304,6310,3130,2980
E,6110,4652,6129,6129,6310,3280,3130,3130
E,6110,4665,4652,4652,6310,4664,3280,3280
E,6111,6110,4665,4665,6311,6310,4664,4664
E,6111,6112,4678,4665,6311,6312,4677,4664
RP4,1,1,13,13,1,1,13,13
E,6063,6069,6068,6062,6263,6269,6268,6262
EGEN,8,6,-1
EGEN,5,1,-8
E,6239,6439,6261,6261,6238,6438,6260,6260
EGEN,2,-1,-1
E,6237,6437,6259,6259,6257,6457,6258,6258
E,6257,6457,6258,6258,6255,6455,6256,6256
E,6255,6455,6256,6256,6253,6453,6254,6254
E,6253,6453,6254,6254,6251,6451,6252,6252
E,4450,6240,6440,6440,4437,6241,6441,6441
RP4,-13,1,1,1,-13,1,1,1
E,4450,6440,6640,4449,4437,6441,6641,4436
RP4,-13,1,1,-13,-13,1,1,-13
E,1180,6444,6244,6244,1330,6446,6246,6246
E,1330,6246,6446,6446,1480,6247,6447,6447
```

TABLE D-1
(Continued)

```
E,6444,6446,1330,1180,6644,6646,1329,1179
RP2,2,1,150,150,2,1,150,150
E,1480,6247,6447,6447,1630,6249,6449,6449
E,6249,6449,1630,1630,6251,6451,1780,1780
E,6447,6449,1630,1480,6647,6649,1629,1479
RP2,2,2,150,150,2,2,150,150
E,4397,1179,6644,6644,4398,1030,6444,6444
E,6244,4398,6444,6444,1180,1180,1180,1180
E,6252,6451,6251,6251,1780,1780,1780,1780
C***
C***  FILLET ELEMS
C***
TYPE,7
MAT,3
E,6262,1930,1929,7001,6268,2080,2079,7002
RP8,6,150,150,1,6,150,150,1
E,7001,6262,6263,6263,7002,6268,6269,6269
RP8,1,6,6,6,1,6,6,6
E,7016,4676,4677,6312,7009,4663,4664,6311
E,6312,4677,4676,7016,6313,4690,4689,7017
RP3,1,13,13,1,1,13,13,1
E,6306,7016,6312,6312,6307,7017,6313,6313
RP3,1,1,1,1,1,1,1,1
E,6264,6263,7001,7001,6270,6269,7002,7002
RP7,6,6,1,1,6,6,1,1
E,6306,6305,7008,7008,7016,6311,7009,7009
E,1780,1930,1929,1779,6252,6262,7001,6451
E,1780,6451,1779,1779,6651,6651,6651,6651
E,6263,6264,7001,7001,6254,6254,6254,6254
E,6451,6453,6254,6254,7001,7001,7001,7001
E,3279,3130,3129,3129,7009,7009,7009,7009
E,3279,3280,4663,4663,7009,7009,7009,7009
E,4663,3280,7009,7009,4664,4664,4664,4664
/GOPR
C***
C***  WAVE RE-ORDERING
C***
WSTART,2,49,47
WSTART,902,973,1
WMORE,998,1045,1
WMORE,5155,5157,1
WMORE,5255,5257,1
WMORE,4352,4352,1
WMORE,4365,4365,1
WMORE,4378,4380,1
WMORE,4386,4386,1
WMORE,4391,4399,1
WMORE,4404,4412,1
WMORE,4417,4425,1
WMORE,4430,4438,1
WMORE,4443,4451,1
WSTART,1952,2023,1
WMORE,2048,2095,1
WMORE,5331,5531,100
WMORE,5228,5230,1
WMORE,5128,5130,1
WMORE,5028,5030,1
WMORE,7002,7002,1
WMORE,6268,6273,1
WMORE,6068,6073,1
WSTART,3452,3499,1
WAVES
```

TABLE D-2
ANSYS PREP7 INPUT LISTING FOR
3-D MODEL LOAD CASE 1 - PURE TENSILE LOAD

```
/PREP7
/NOPR
/TITLE,  ALCOA TANK SHOE    -    TENSILE LOADING  CASE 5
ET,1,45,......,1          *** SHAFT
ET,2,45,......,1          *** RUBBER BUSHING
ET,3,45,......,1          *** CYLINDER CASTING
ET,4,45,......,1          *** THICK & THIN BACK PLATES
ET,5,45,......,1          *** WEB & INTERSECTING CYLINDER WALL
ET,6,45,......,1          *** WEB ONLY
ET,7,45,......,1          *** FILLETS
C***   MATL 1  STEEL
EX,1,30.0E6
ALPX,1,0.
NUXY,1,.3
DENS,1,.283
C***  MATL 2   RUBBER
EX,2,4.0E3
ALPX,2,0.
NUXY,2,0.
DENS,2,.0336
C***  MATL 3  ALUMINUM
EX,3,10.0E6
ALPX,3,0.
NUXY,3,.33
DENS,3,.098
C***
C***   <------   INSERT GEOMETRY CARDS  HERE
C***
CPSIZE,50
PRSTR,-1,1,2,3,4,5,6,7
TIME,0
ITER,1,1,1
LPRINT,1
KRF,2
KTEMP,0
TREF,0
TUNIF,70.
SYMBC,0,2,3.769
SYMBC,0,3,11.870
D,4709,UX,0.
CPNGEN,1,UY,2,49,1
CPNGEN,2,UY,3902,3949,1
CPNGEN,3,UZ,2,49,1
F,2,FY,-18000.
F,3902,FY,-18000.
LWRITE
AFWRITE
FINISH
```

TABLE D-3
ANSYS PREP7 Input Listing for
3-D Model Load Case 2 - Out-of-Plane Load

```
/PREP7
/NOPR
/TITLE,  ALCOA TANK SHOE     -     BENDING LOAD
ET,1,45,,,,,,,1          ***  SHAFT
ET,2,45,,,,,,,1          ***  RUBBER BUSHING
ET,3,45,,,,,,,1          ***  CYLINDER CASTING
ET,4,45,,,,,,,1          ***  THICK BACK PLATE
ET,5,45,,,,,,,1          ***  WEB & INTERSECTING CYLINDER WAL
ET,6,45,,,,,,,1          ***  WEB ONLY
ET,7,45,,,,,,,1          ***  FILLETS
C***   MATL 1  STEEL
EX,1,30.0E6
ALPX,1,0.
NUXY,1,.3
DENS,1,.283
C***  MATL 2   RUBBER
EX,2,4.0E3
ALPX,2,0.
NUXY,2,0.
DENS,2,.0336
C***  MATL 3  ALUMINUM
EX,3,10.0E6
ALPX,3,0.
NUXY,3,.33
DENS,3,.098
C***
C***   <----- INSERT GEOMETRY HERE
C***
CPSIZE,50
PRSTR,-1,1,2,3,4,5,6,7
TIME,0
ITER,1,1,1
LPRINT,1
KRF,2
KTEMP,0
TREF,0
TUNIF,70.
SYMBC,0,2,3.769
SYMBC,0,3,11.870
D,6266,UX,0.,,6267,1
RP8,6,,,,6
D,6259,UX,0.,,6261,1
D,6401,UX,0.,,6416,1
D,6424,UX,0.,,6429,1
D,6437,UX,0.,,6439,1
D,6627,UX,0.,,6629,1
D,6637,UX,0.
D,6640,UX,0.,,6642,1
CPNGEN,1,UY,2,49,1
CPNGEN,2,UY,3902,3949,1
CPNGEN,3,UZ,2,49,1
CPNGEN,4,UX,2,49,1
CPNGEN,5,UX,3902,3949,1
F,2,FX,9000.
F,3902,FX,9000.
F,2,FY,-15588.
F,3902,FY,-15588.
LWRITE
AFWRITE
FINISH
```

TABLE D-4
ANSYS PREP7 INPUT LISTING FOR
3-D MODEL LOAD CASE 3 - TWISTING LOAD

```
/PREP7
/NOPR
/TITLE,  ALCOA TANK SHOE      -    TWIST LOADING
ET,1,45,.......1          ***  SHAFT
ET,2,45,.......1          ***  RUBBER BUSHING
ET,3,45,.......1          ***  CYLINDER CASTING
ET,4,45,.......1          ***  THICK BACK PLATE
ET,5,45,.......1          ***  WEB & INTERSECTING CYLINDER WALL
ET,6,45,.......1          ***  WEB ONLY
ET,7,45,.......1          ***  FILLETS
C***  MATL 1  STEEL
EX,1,30.0E6
ALPX,1,0.
NUXY,1,.3
DENS,1,.283
C***  MATL 2   RUBBER
EX,2,4.0E3
ALPX,2,0.
NUXY,2,0.
DENS,2,.0336
C***  MATL 3  ALUMINUM
EX,3,10.0E6
ALPX,3,0.
NUXY,3,.33
DENS,3,.098
C***
C***   <------  INSERT GEOMETRY CARDS HERE
C***
CPSIZE,50
PRSTR,-1,1,2,3,4,5,6,7
TIME,0
ITER,1,1,1
LPRINT,1
KRF,2
KTEMP,0
TREF,0
TUNIF,70.
ASYMBC,0,2,3.769
ASYMBC,0,3,11.870
D,2,UY,0.
CPNGEN,1,UX,2,49,1
CPNGEN,2,UZ,2,49,1
F,2,FX,18000.
LWRITE
AFWRITE
FINISH
```

DEAC

TABLE D-5

ANSYS POST1 INPUT LISTING FOR POSTPROCESSING
3-D MODEL RESULTS (MAXIMUM STRESS SUMMARIES,
DISPLACEMENT AND STRESS CONTOUR PLOTS)

```
SET DEF [KAHRS2]
ANSYS
/POST1
/TITLE, TRAK SHOE, TWIST LOAD
STRESS,SIG1,45,101
,SIG2,45,102
,SIG3,45,103
,SINT,45,104
,SIGE,45,105
SET,1,1
*SET,NTYP,1,1
*BEGIN,MAC
ERSEL,TYPE,NTYP
NELEM
ESORT,SINT,,,15
PRSTRS
PRELEM
EUSORT
NSORT,SI,,,15
PRNSTR,PRIN
NALL
EALL
*END
*DO,MAC,1,6
ERSEL,TYPE,1
NELEM
PRNSTR,ALL
NALL
EALL
ERSEL,TYPE,2
NELEM
PRNSTR,ALL
NALL
EALL
ERSEL,TYPE,3,7,1
NELEM
PRNSTR,ALL
NALL
EALL
GLOBAL,1
PRRFOR
/TYPE,1,1
/TITLE, DISP. - VERT. PLANE THRU CL OF SHAFT - TWIST LOAD
/DSCALE,1,1
/VIEW,1,,1
/FOCUS,,,1.3
/ANG,,90
NALL
EALL
PLDISP
/ANG,,180
/TITLE, DISP. - HOR. PLANE THRU CL OF SHAFT - TWIST LOAD
/VIEW,1,1
/FOCUS,,1.8
NALL
EALL
PLDISP
```

TABLE D-5
(Continued)

```
/TYPE,1,1
/TITLE, DISP. - VERT. PLANE THRU CL OF SHAFT - TWIST LOAD
/DSCALE
/VIEW,1,,1
/FOCUS,,,1.3
/ANG,,90
NALL
EALL
PLDISP
/ANG,,180
/TITLE, DISP. - HOR. PLANE THRU CL OF SHAFT - TWIST LOAD
/VIEW,1,1
/FOCUS,,1.8
NALL
EALL
PLDISP
/TITLE, DISP. - HOR. PLANE THRU CENTER OF WEB - TWIST LOAD
/FOCUS,,.895
NALL
EALL
PLDISP
/TITLE, DISP. - LAT. PLANE THK. (OUTER) PLATE - TWIST LOAD
/VIEW,1,,,-1
/FOCUS,,,,1.55
/ANG,,-90
NALL
EALL
PLDISP
/TITLE, DISP. - LAT. PLANE THRU CL OF SHOE - TWIST LOAD
/FOCUS,,,,6.23
NALL
EALL
PLDISP
/TITLE, DISP. - LAT. PLANE THRU  THIN PLATE - TWIST LOAD
/FOCUS,,,,10.91
NALL
EALL
PLDISP
/CLABEL,1,1
/CONTOUR,1,10
/FOCUS,,,1.3
/ANG,,90
/VIEW,1,,1
/EDGE,1,1
/DSCALE,,1
/TITLE, SI - VERT. PLANE THRU CL OF SHAFT - TWIST LOAD
NALL
EALL
ERSEL,TYPE,3,7,1
PLNSTR,SI
/FOCUS,,1.8
/VIEW,1,1
/TITLE, SI - HOR. PLANE THRU CL OF SHART - TWIST LOAD
NALL
EALL
ERSEL,TYPE,3,7,1
/ANG,,180
```

TABLE D-5
(Continued)

```
PLNSTR,SI
/FOCUS,,,.895
/TITLE, SI - HOR. PLANE THRU CENTER OF WEB - TUIST LOAD
NALL
EALL
ERSEL,TYPE,3,7,1
PLNSTR,SI
/FOCUS,,,,1.55
/VIEW,1,,,-1
/TITLE, SI - LAT. PLANE THRU THK. (OUTER) PLATE - TUIST LOA
D
NALL
EALL
ERSEL,TYPE,3,7,1
/ANG,,-90
PLNSTR,SI
/TITLE, SIG1 - LAT. PLANE THRU THK. (OUTER) PLATE - TUIST L
OAD
PLNSTR,SIG1
/TITLE, SIG3 - LAT. PLANE THRU THK. (OUTER) PLATE - TUIST L
OAD
PLNSTR,SIG3
/FOCUS,,,,6.23
/TITLE, SI - LAT. PLANE THRU CENTERLINE OF SHOE - TUIST LOA
D
NALL
EALL
ERSEL,TYPE,3,7,1
PLNSTR,SI
/FOCUS,,,,10.91
/TITLE, SI - LAT. PLANE THRU THIN (BTUN. SHOES) PLATE - TUI
ST LOAD
NALL
EALL
ERSEL,TYPE,3,7,1
PLNSTR,SI
/TITLE
/TITLE, SIG1 - LAT. PLANE THRU THIN (BTUN. SHOES) PLATE - T
UIST LOAD
PLNSTR,SIG1
/TITLE, SIG3 - LAT. PLANE THRU THIN (BTUN. SHOES) PLATE - T
UIST LOAD
PLNSTR,SIG3
NALL
EALL
/RESET
/TITLE, HIDDEN LINE DISP. PLOT OF HALF-SYMM SHOE MODEL - TU
IST LOAD
/TYPE,1,2
/VIEW,1,1,1,-.7
/ANG,,180
PLDISP
/VIEW,1,1,-1,.7
/ANG
PLDISP
/TITLE, HIDDEN LINE SI PLOT OF HALF-SYMM SHOE MODEL - TUIST
LOAD
```

TABLE D-5
(Continued)

```
/CLABEL,1,1
/CONTOUR,1,10
/EDGE,1,1
PLNSTR,SI
/EDGE
/CONTOUR,,-1
ERSEL,TYPE,1,2
/TITLE, HIDDEN LINE DISP. PLOT, SHAFT/RUBBER ONLY - TWIST L
OAD
PLDISP
FINISH
```